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MUZZLE BLAST MEASUREMENTS
ON HOWITZER, 105mm, XM103E1

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
MARYLAND

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Abstract

Measurements of muzzle-blast in the crew area of the 105mm Howitzer, XM103, without a muzzle brake and with muzzle brakes WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), and WTV-D8259 (Low Efficiency), were made to determine the peak overpressures produced. The overpressures produced by the four different brake conditions were one of the most important factors determining which brake would be used on the XM102 Howitzer. The howitzer was fired at elevations of 2, 45, and 62 - 68 degrees. It is recommended that the 5/K (Medium Efficiency) Brake is the maximum efficiency brake to be considered for this weapon. The Watertown Blast Shield provided for this program is not recommended for this weapon. It is recommended that wearing V51R earplugs should be mandatory for all personnel located in the crew area when the 105mm Howitzer, XM102, is fired. It is also recommended that future work on the muzzle-blast problem follow the recommendations of Professor Slade, as described in the National Defense Research Committee Report No. A-391, "Muzzle Blast: Its Characteristics, Effects, and Control", 1946.

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TABLES (cont'd)

MUZZLE BLAST MEASUREMENTS

ON HOWITZER, 105mm, XM103E1

Introduction

The 105mm Howitzer, XM103E1, is an experimental weapon being used in the development of the 105mm Howitzer, XM102, which, in turn, is being developed to provide the U. S. Army with a weapon which possesses greater firing range and less weight than the 105mm howitzers presently used. Weight becomes a problem when moving weapons by aircraft, and particularly when moving them by helicopter. Greater firing range is required to provide infantry support from a position farther from the enemy's artillery.

Lightweight metals, such as aluminum and magnesium are used in the newer weapons to obtain a lightweight weapon. Another way to decrease weight is to use an attachment on the muzzle of the howitzer tube, an attachment known as a muzzle brake. Figure 1 shows the 105mm Howitzer, XM102, with a brake attached to the muzzle of the tube. When the howitzer is fired, some of the gases which propel the projectile through the tube are deflected to the side and to the rear of the muzzle. This occurs as the base of the projectile passes through the open part, or port, of the brake. When the projectile is in this position, the main avenue of escape for the propelling gases is through the ports in the muzzle brake. The turning action of the gases in the brake exerts a forward force on the brake which acts against the recoiling force that is pushing the tube to the rear. This weapon still requires a hydraulic recoil system, but a lighter one suffices because the muzzle brake has reduced the recoiling force. The muzzle brake helps reduce the weight of the howitzer, but it creates a problem by greatly increasing the overpressure in the crew area behind the muzzle. This increased overpressure not only has harmful physiological and psychological effects on the crew, but it often creates more dust and hurls loose objects (such as stones) along the ground, particularly when the weapon is "dug in" in a tactical situation.

Although muzzle brakes have been considered in many places for many years, the Germans were the first, during World War II, to make extensive use of them (1). The British used brakes to mount 57mm and 3 in. guns on light carriages, and the Americans used them in an attempt to reduce obscuration from dust and to reduce muzzle flash.

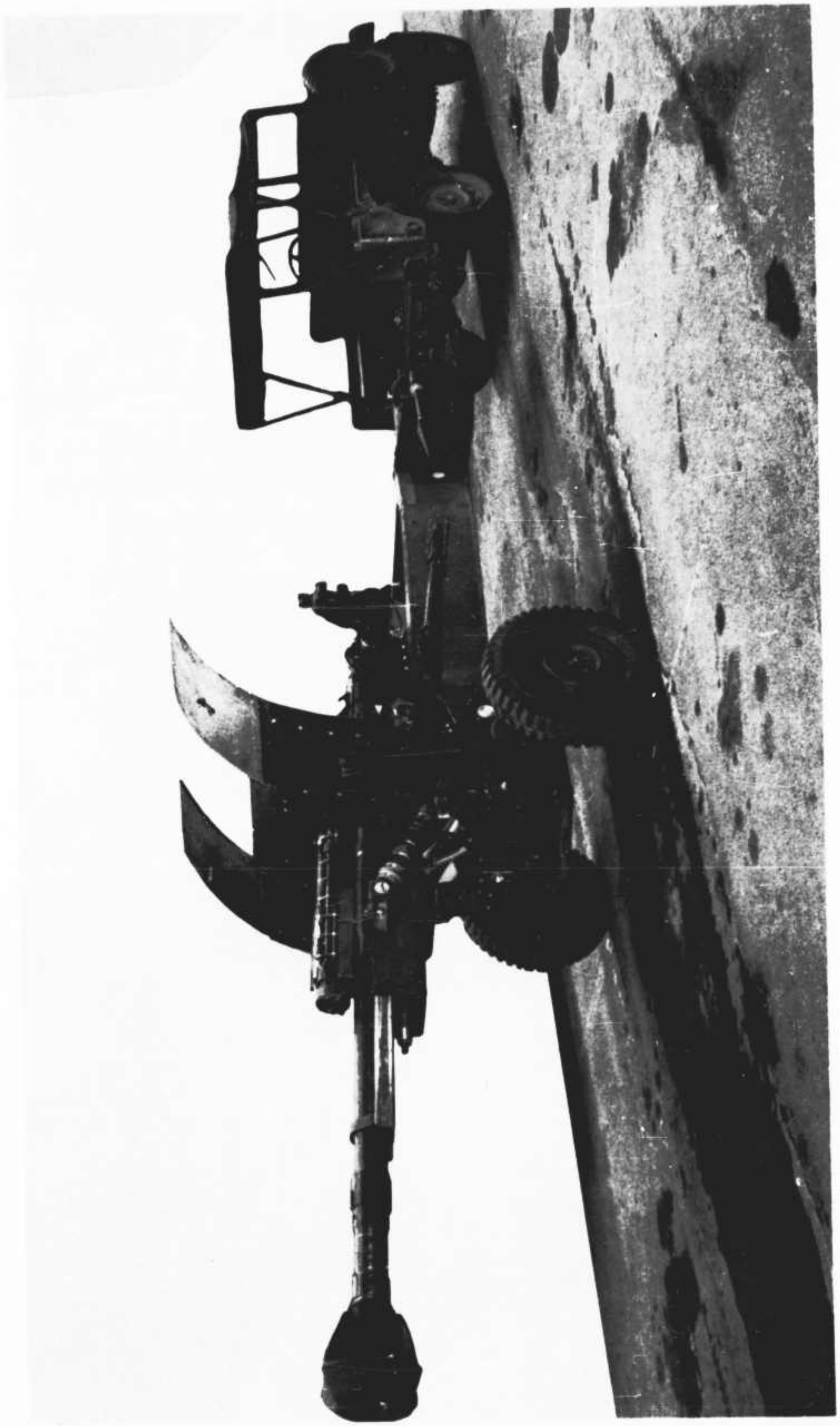

Fig. 1. 105mm HOWITZER, XM102, TOWED

The principal measurements made in the crew area of the XM103 Howitzer, were peak overpressures. Most of the overpressures were incident overpressures*, but a few were reflected overpressures**. The blast gages were placed on one side of the line of fire (center line through the breech, tube, and muzzle), rather than on both sides, since the howitzer was symmetrical about the line of fire. It was decided to obtain measurements at 16 locations on one side in order to accurately map the overpressure patterns on one side, rather than measure at eight locations on each side and obtain less accurate patterns on both sides. Admittedly, this procedure neglects the effect of crosswind, but wind is something that cannot be controlled in the field.

The howitzer was fired at elevations of 34, 37, and 40 mils (approximately 2 degrees); 800 mils (45 degrees); and 1100, 1150, and 1200 mils (approximately 62, 65, and 68 degrees respectively) with three different muzzle brakes and without a muzzle brake. The three muzzle brakes are shown in Fig. 2. Three XM57E2 propelling charges, Zone 9, Zone 10, and Zone 11, were fired at the 1100-1200-mil elevation and two XM57E2 propelling charges, Zone 10 and Zone 11, were fired at the 34-40-mil elevation and the 800-mil elevation. The XM57E2 charge varies in size and weight in increments from one (Zone 6) to six (Zone 11) to meet the military characteristics of chamber pressure and muzzle velocity to propel the projectile to varying ranges. A Zone 6 charge consists of only the first increment, whereas the Zone 11 charge consists of all six increments. The Zone 11 charge produces the greatest chamber pressure (100%, or maximum rated pressure) and the greatest muzzle velocity of the six XM57E2 charges. The Zone 10 charge is an 85% charge, and the Zone 9 charge is a 50% charge. One hundred and sixty-six rounds were fired during the program to provide at least two rounds for each combination of conditions - elevation, muzzle brake, blast shield, and propelling charge. One hundred and eighteen rounds were fired without the blast shield, and 48 rounds were fired with the blast shield mounted on the howitzer.

The blast shield used in this program was developed by Watertown Arsenal; it is shown in Fig. 3. This shield was intended to protect the crew from muzzle blast.

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* Incident Overpressure: The transient pressure, usually expressed in pounds per square inch (psi), exceeding the ambient pressure, manifested in the shock (or blast) wave which has moved outward from the explosion source through air without reflecting from any surface, e.g., the ground. The variation of the overpressure with time depends on the energy yield of the explosion and the distance from the howitzer muzzle. The peak overpressure is the maximum value of the overpressure at a given location and is generally experienced at the instant the shock (or blast) wave reaches that location.

** Reflected Overpressure: The transient pressure exceeding the ambient pressure, manifested in the shock (or blast) wave which has reflected from some surface. The magnitude of the reflected overpressure depends on the strength of the incident shock wave and the angle at which it strikes the surface.

High Efficiency Brake WTV-F 8241

Medium Efficiency Brake 5/K

Low Efficiency Brake WTV-D 8259

Fig 2. MUZZLE BRAKES TESTED ON HOWITZER, 105mm, XM103E1

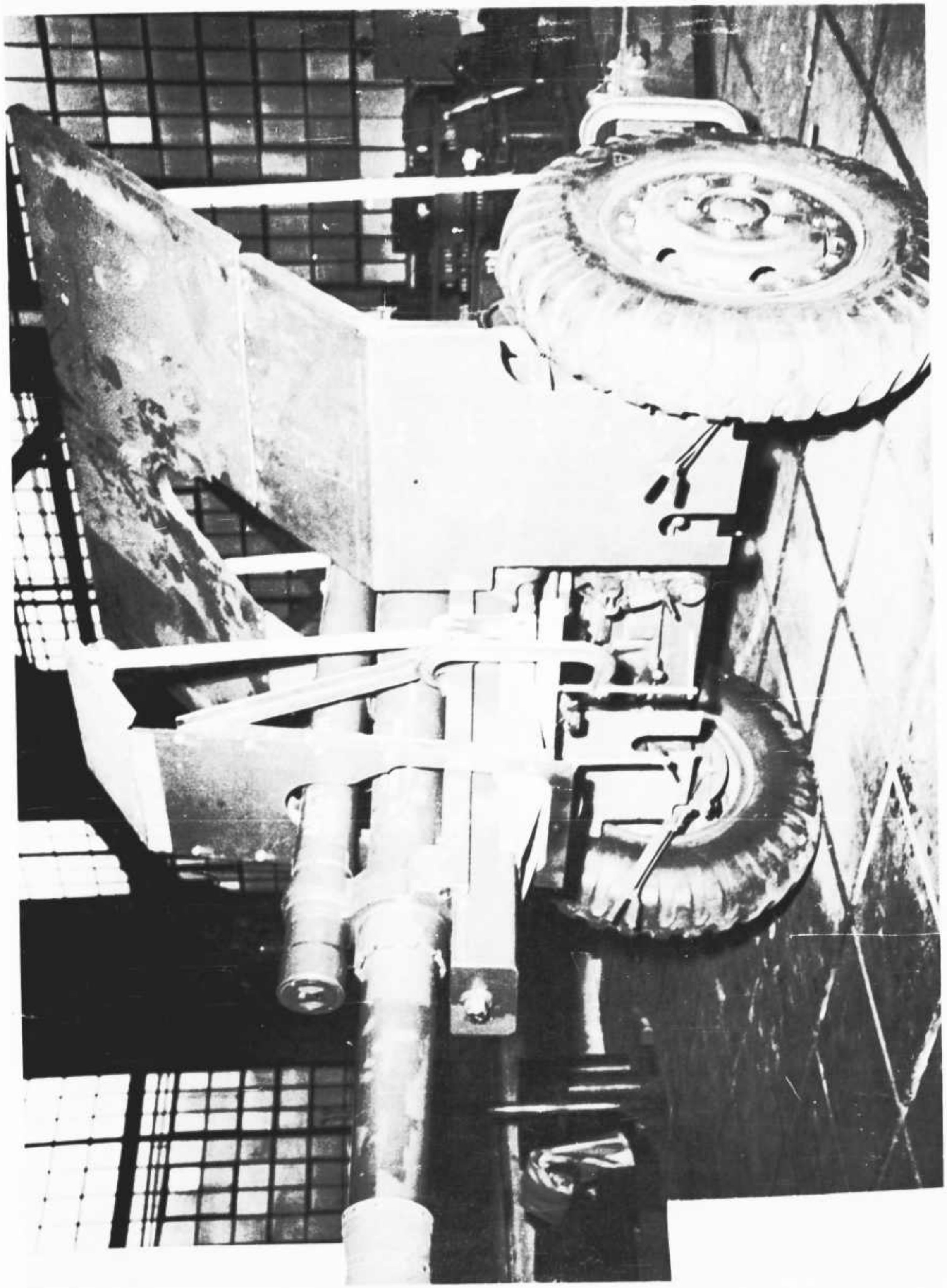


Fig. 3. WATERTOWN ARSENAL BLAST SHIELD ON 105mm HOWITZER CARRIAGE M2A2

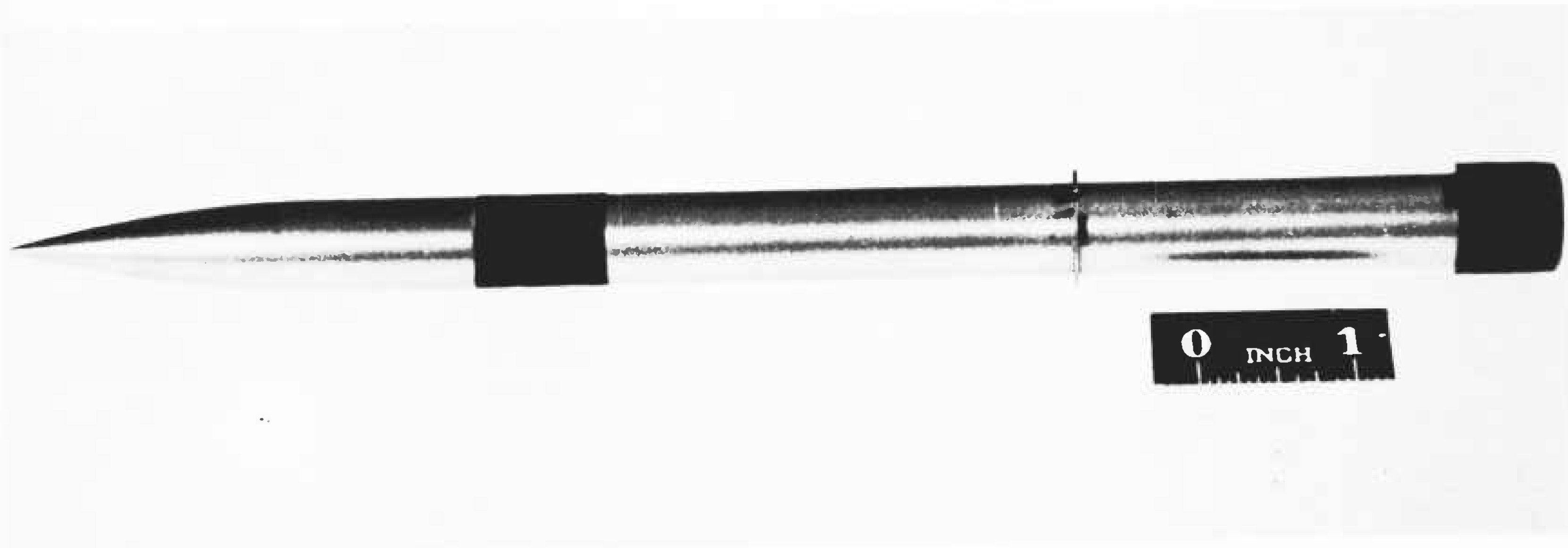


Fig. 4. ATLANTIC RESEARCH CORPORATION TYPE LC-33C BLAST GAGE

Procedure

Measurements were made in an open area at the Plate Range, Aberdeen Proving Ground, Maryland, during the period 25 January - 9 February 1962. The open area was selected to minimize reflection of the muzzle blasts from surfaces other than the ground and the howitzer itself.

The weapon used to produce the muzzle blasts was the Howitzer, 105mm, XM103E1, Serial No. 1 composed of:

Tube, 105mm, XM103E1, Serial No. 1A
Carriage, 105mm, M2A2E2, Serial No. 1, with blast shield
Carriage, 105mm, M2A2E2, Serial No. 6, without blast shield
Recoil System, 105mm, M2A4, Serial No. 13756, with blast shield
Recoil System, 105mm, M2A3, Serial No. 151, without blast shield
Propellant, XM57E2, White Bag, Lot PA-E-34488
Projectile, 105mm, T388 (M442), Inert
Primer, M28B2E2, Lot PA-E-34363
Muzzle Brake WTV-F8241 (High Efficiency)
Muzzle Brake 5/K (Medium Efficiency)
Muzzle Brake WTV-D8259 (Low Efficiency)
Blast Shield, Watertown Arsenal Sketch WA-90

Eight Atlantic Research Corporation Type LC-33C blast gages were used to sense the transient hydrostatic pressure produced by each muzzle blast. This type of gage (Fig. 4) is pencil-shaped, ten inches long and 5/8 inch in diameter, with a cylindrical sensitive element of piezoelectric zirconate. The cylinder is mounted on a spindle under a neoprene cover which is flush with the outer surface. The gage body is streamlined to reduce turbulence and improve the air flow past the sensing element. The sensitivity or calibration factor (K_a) of this gage is approximately 1200 micromicrocoulombs/psi.

The recording system, which was constructed by the Instrumentation Laboratory of the Development and Proof Services (D&PS), Aberdeen Proving Ground, Maryland, consisted of wide band (1 to 100,000 cps) response amplifiers, cathode-ray tubes, charge calibrators, time standards (0.1 and 1.0 millisecond intervals), General Radio Model 651 cameras, and sequence timers. This system was installed in a semi-trailer located about 300 feet away from the howitzer.

On 24 and 25 January 1962, each blast gage was calibrated at the pressure level expected to be encountered at its position during the firing of the weapon, which took place during the period 25 January - 9 February 1962. Calibrations were made by subjecting the gages to detonations of bare charges of spherical pentolite. Four gages were exposed to a blast simultaneously by placing them in a circle, 90 degrees apart, with the gages pointed toward the pentolite, which was suspended in the center of the circle at the same height as the gages.

A pair of velocity gages was used with each blast gage to obtain the shock-front velocity. The velocity of the shock front obtained from each blast was recorded in the instrumentation trailer. Simultaneously, a trace of the blast overpressure at each blast gage for the duration of the blast was obtained on camera film. The shock-front velocity was used in the following Rankine-Hugoniot equation, modified for wind effect, to obtain a numerical value of the peak overpressure.

$$P = \frac{2 \gamma P_o}{\gamma + 1} \left[\frac{(V \pm K)^2}{C^2} - 1 \right]$$

where,
P = peak overpressure (psi)
P_o = ambient pressure (psi)
γ = ratio of specific heats = 7/5 for air
V = shock velocity (fps)
C = ambient sound velocity (fps)
K = wind effect correction (fps)

The peak overpressure obtained from the Rankine-Hugoniot equation was applied to the recorded peak overpressure obtained from the camera film to obtain a gage constant which was used in the reduction of the muzzle blast records. The gage constant was calculated for each blast gage as follows:

$$K_a = \frac{Q\, D_p\, (10^{-6})}{D_c\, P} = \frac{C\, v\, D_p\, (10^{-6})}{D_c\, P}$$

where,
K_a = gage constant (uuc/psi)
Q = Cv = calibration charge (uc)
C = calibration capacitance (uf)
v = voltage (volts)
D_p = peak deflection measurement
D_c = calibration deflection measurement
P = pressure computed from shock velocity (psi)

For a quantitative analysis of the film record, calibration "steps" must be placed on the film immediately prior to firing (detonation of the pentolite charge)(2). These "steps" represent precise electrical values which are calculated in advance and adjusted by calibrated capacitance decades to represent a value approximately equal to the expected signal output from the gage. This charge value is represented by Q in the preceding K_a equation.

The blast gages were placed in the 16 locations shown in Fig. 5. These positions were selected to include the crew positions when the howitzer is fired. The gage heights varied from 60 to 77 inches above the ground. These heights were selected as nearly representative of the average ear height of Army personnel. No tests for variation of overpressure were made as a function of height.

The howitzer was fired at a low elevation of approximately 2 degrees, an intermediate elevation of 45 degrees, and a high elevation varying from approximately 62 to 68 degrees. The variation at the high elevation was due to the blast shield. With the blast shield mounted on the howitzer, the shield prevented the tube returning to "battery" or firing position after recoil at the 68 degree elevation. The howitzer was "dug in" so that the center of the trunnions was 30 inches above the ground.

The gages were located relative to a stake in the ground directly below the muzzle (without a brake) when the howitzer elevation was 0 degrees (Fig 5). The gages were pointed toward the muzzle for all firings (Fig. 6). When the howitzer elevation was changed from 2 degrees to 45 degrees and from 45 degrees to 62 - 68 degrees and vice-versa, the direction of the gages was also changed so that the gages pointed toward the muzzle. The change in direction of the gages also changed the horizontal distance of the gages from the reference stake, which necessitated distance measurements from the reference stake to the gages for each change in howitzer elevation.

Immediately before the firing of each round, charge or calibration "steps" were applied to the gage lines by the charge calibrator. The values of these "steps" were adjusted by calibrated capacitance decades corresponding to the expected values developed by the gages. The capacitance of the cables connecting the decades was measured and included in the charge-step calculations.

Data

The average peak overpressure values are presented in tabular form in Tables 1 - 4 and graphically in the Appendix. While measurements were obtained on only one side of the howitzer, the peak overpressures have been plotted on both sides in order to show the overpressure values relative to the crew positions.

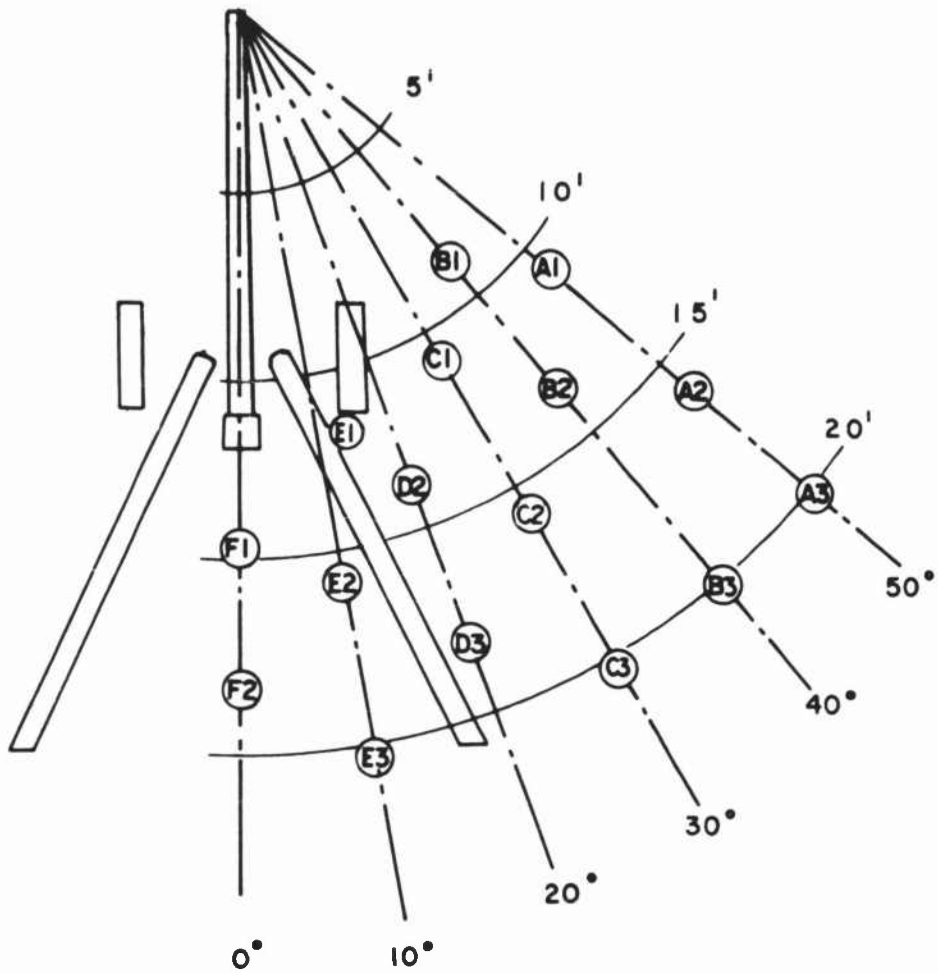


Fig. 5. BLAST GAGE LOCATIONS FOR HOWITZER, 105mm, XM103E1

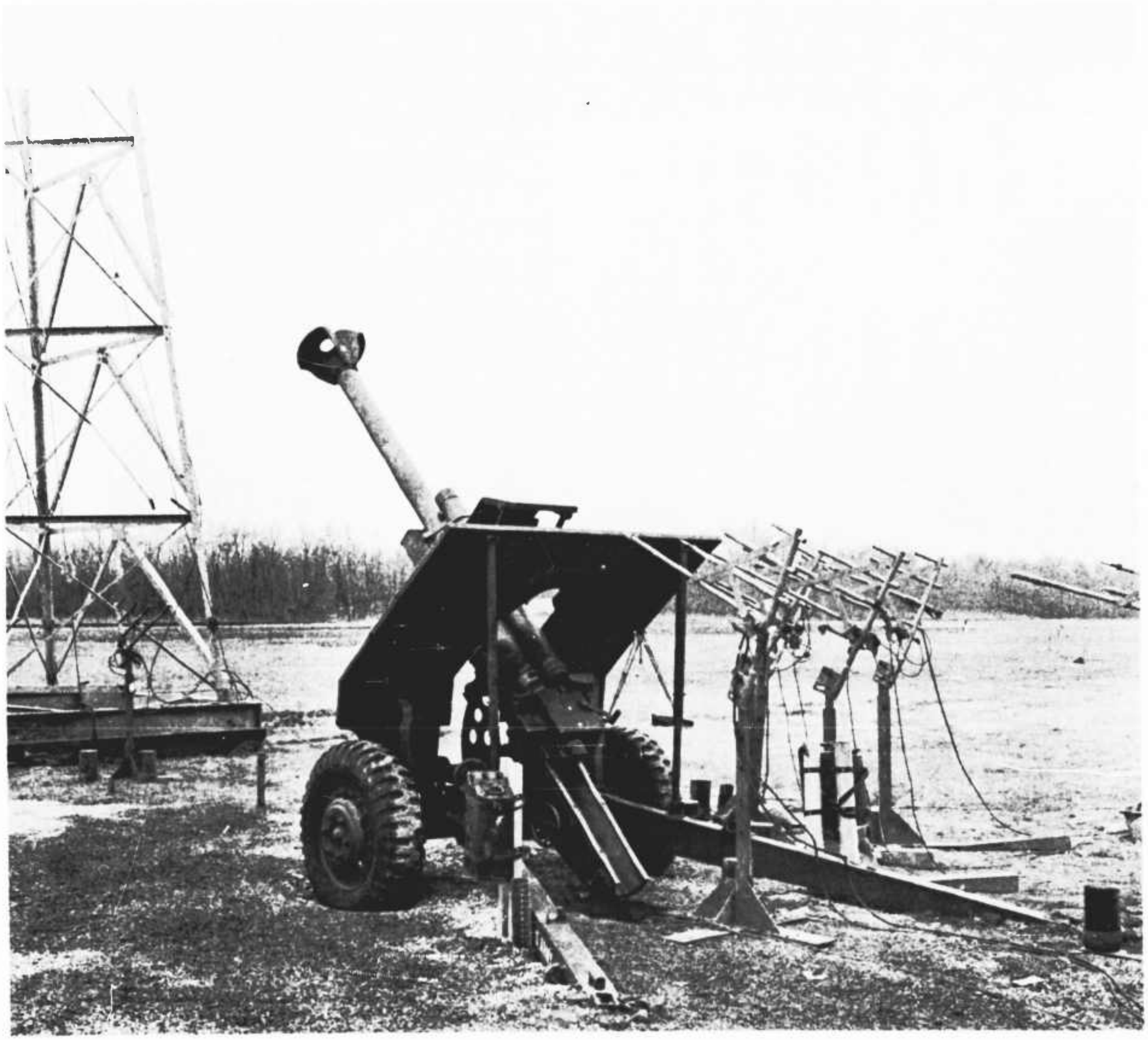


Fig. 6. VIEW OF GAGES POINTED TOWARD MUZZLE, 45° HOWITZER ELEVATION

TABLE 1

Summary of Peak Overpressures

At Crew Positions for Howitzer, 105mm, XM103

With High Efficiency Brake WTV-F8241

Propelling Charge Zone	Blast Shield	Peak Overpressure in psi at Positions Noted[a] CS	G	1	2	3	4	5
				Elevation 2°				
10	No	2.1[b]	5.5	5.3	3.2	3.4	3.5	3.6
11	No	2.3[b]	5.6	5.1	3.6	3.6	3.8	3.6
	Yes	1.7[b]	5.4	3.6	3.9	3.0	4.0	3.9
				Elevation 45°				
10	No	2.5	7.2	6.8	4.3	4.0	4.6	3.6
11	No	2.5	7.0	6.4	5.0	4.0	4.4	3.5
	Yes	2.0[b]	7.0	6.3	3.6	4.1	5.2	3.8
				Elevation 62-68°				
9	No	1.6	4.9	4.8	3.0	2.8	3.4	2.4
10	No	3.6	7.8	7.7	5.0	4.5	5.4	3.7
11	No	3.4	8.6[b]	7.9	5.4	5.3	6.3	4.1
	Yes	2.7	7.8[b]	7.0	5.2	5.0	6.1	4.3

[a] Positions determined from FM 6-75, "105mm Howitzer, M2 Series, Towed"

[b] Estimated values

TABLE 2

Summary of Peak Overpressures

At Crew Positions for Howitzer, 105mm, XM103

With Medium Efficiency Brake 5/K

Propelling Charge Zone	Blast Shield	Peak Overpressure in psi at Positions Noted[a]						
		CS	G	1	2	3	4	5
				Elevation 2°				
10	No	1.7[b]	3.5	3.4	2.5	3.3	2.5	2.6
11	No	1.5[b]	3.7	3.5	2.9	3.5	2.8	2.8
	Yes	1.4[b]	4.3	2.6	2.9	2.9	3.3	2.9
				Elevation 45°				
10	No	2.0	4.6	4.0	3.4	3.0	3.3	3.0
11	No	2.2[b]	5.3	4.7	3.5	3.7	3.8	3.0
	Yes	1.8[b]	5.7[b]	4.9[b]	3.2	3.3	3.8	2.8
				Elevation 62-68°				
9	No	1.5	3.1	2.9	2.4	2.1	2.3	2.0
10	No	2.6	6.0	5.6	3.9	4.1	4.6	3.0
11	No	2.9	6.5[b]	5.9[b]	4.6	4.2	4.6	2.5
	Yes	2.1	5.7[b]	5.0	3.6	3.7	4.4	3.5

[a] Positions determined from FM 6-75, "105mm Howitzer, M2 Series, Towed"

[b] Estimated values

TABLE 3

Summary of Peak Overpressures

At Crew Positions for Howitzer, 105mm, XM103

With Low Efficiency Brake WTV-DB8259

Propelling Charge Zone	Blast Shield	Peak Overpressure in psi at Positions Noted[a]						
		CS	G	1	2	3	4	5
				Elevation 2^{o}				
10	No	1.0	2.9	2.8	1.8	2.2	1.8	2.2
11	No	1.3[b]	3.0	2.8	2.0	2.3	2.2	2.0
	Yes	0.9[b]	2.6	1.7	2.0	2.0	1.7	2.2
				Elevation 45^{o}				
10	No	1.4	3.2	3.2	2.3	2.8	2.3	2.2
11	No	1.4	3.5	3.0	2.2	2.6	2.8	2.3
	Yes	1.3	3.8[b]	3.0[b]	2.5	2.4	2.9	2.3
				Elevation $62\text{-}68^{o}$				
9	No	1.1	2.3	2.2	1.6	2.1	2.1	1.5
10	No	1.9	3.8	3.5	2.7	2.8	2.8	2.4
11	No	1.9	3.9[b]	3.8	2.8	3.2	3.1	2.6
	Yes	1.7	3.8[b]	3.4	2.6	2.8	3.1	2.6

[a] Positions determined from FM 6-75, "105mm Howitzer, M2 Series, Towed"
[b] Estimated values

TABLE 4

Summary of Peak Overpressures

At Crew Positions for Howitzer, 105mm, XM103

Without A Brake

Propelling Charge Zone	Blast Shield	Peak Overpressure in psi at Positions Noted[a]						
		CS	G	1	2	3	4	5
				Elevation 2°				
10	No	0.7	1.0	0.9	0.7	0.8	0.8	0.9
11	No	0.7[b]	1.0	1.0	0.7	0.9	0.8	0.9
	Yes	0.3[b]	1.1	0.8	0.5	0.8	0.8	0.9
				Elevation 45°				
10	No	0.7	1.4	1.3	1.0	1.1	1.0	1.1
11	No	0.7	1.4	1.2	0.9	1.1	1.1	1.1
	Yes	0.6[b]	1.3	1.1	0.8	1.1	1.2	1.2
				Elevation 62-68°				
11	No	0.8[b]	1.5	1.3	0.9	1.2	1.3	1.2
	Yes	0.8[b]	1.7[b]	1.6[b]	1.1	1.5	1.3	1.3

[a] Positions determined from FM 6-75, "105mm Howitzer, M2 Series, Towed"
[b] Estimated values

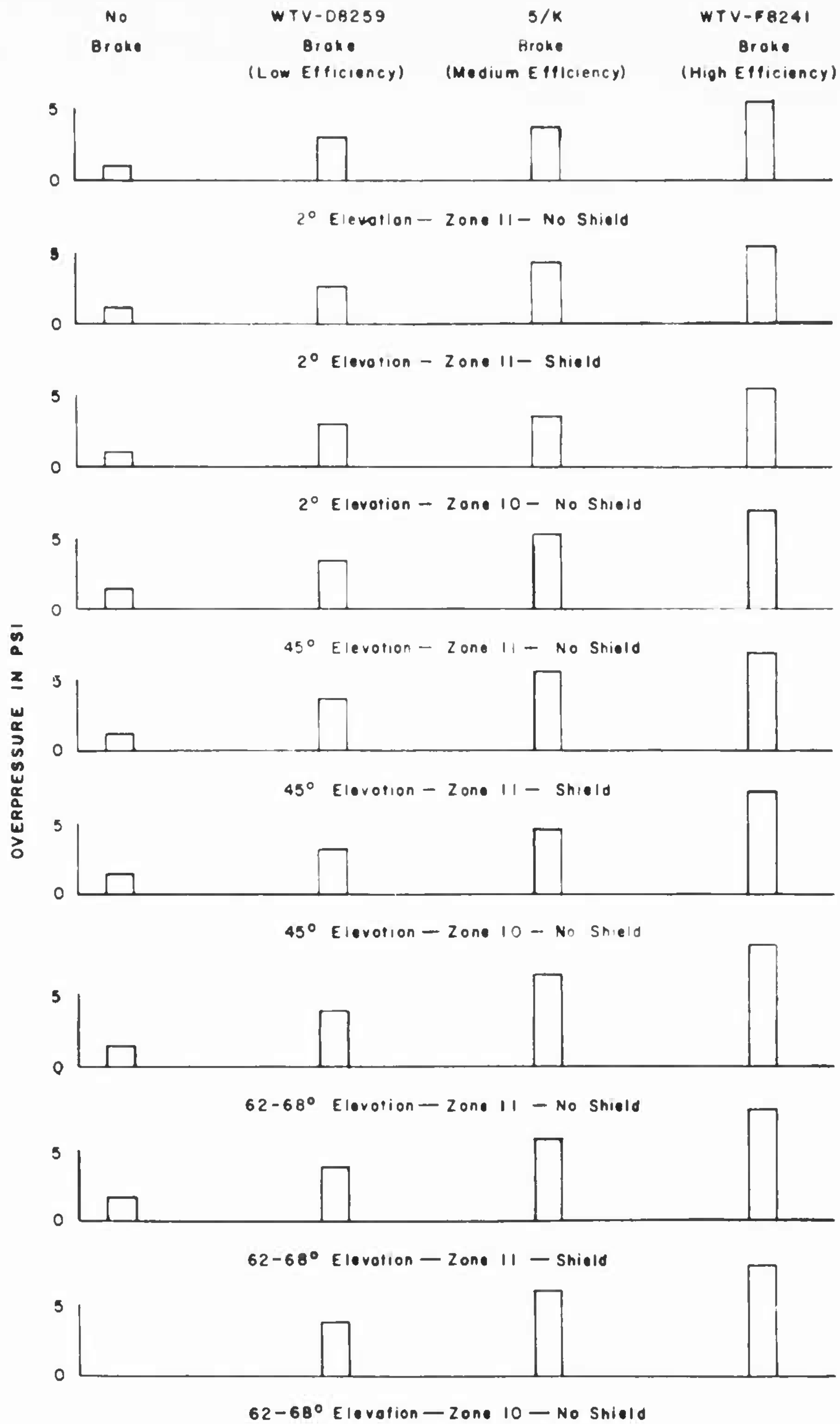


Fig. 7. DIAGRAM SHOWING OVERPRESSURE INCREASE WITH BRAKE EFFICIENCY AT GUNNER'S POSITION (MOST SEVERE) This diagram is typical for all crew positions.

Results

The overpressures shown in Tables 1 - 4 are for the most part slightly different (but not significantly so) from those shown in Table 1 of Human Engineering Laboratories Technical Note 5-62, "A Preliminary Report of Muzzle Blast Measurements on Howitzer, 105mm, XM103", published in May 1962. Table 1 of Technical Note 5-62 shows nine crew positions, while Table 1 - 4 of this memorandum show seven crew positions. The overpressures in Technical Note 5-62 were based on raw data that was reduced using gage calibrations from a previous blast program. This was done because the gage calibrations from the firings for the program (January - February 1962) were not yet available; the old calibrations were used so that preliminary data could be published. The overpressures in the present memorandum were obtained from the same raw data, but the data were reduced with gage calibrations from the January - February firings. A statistical analysis of differences between the preliminary overpressures and the final overpressures was done with the sign test (3), which showed that the differences were not significant. When the preliminary report was written, it was assumed that the XM102 crew consisted of nine men, or the same number of men assigned to the 105mm Howitzer, M2 Series, Towed. Since then it has been learned that this howitzer will be manned by seven men, as specified by the Artillery Board, the Artillery School, and the Continental Army Command.

The results show that overpressures increased with brake efficiency (Fig. 7). The lowest overpressures occurred when no brake was used, and the highest overpressures occurred when the WTV-F8241 (High Efficiency) brake was used. The blast shield did not significantly reduce the overpressures in the crew area (Table 5). In 71 out of 77 cases (11 conditions x 7 crew members), overpressures increased with firing elevation or howitzer elevation as shown in Fig. 8. In five cases, the medium (45 degrees) elevation overpressures were less than the low (2 degrees) and high (62-68 degrees) elevation overpressures. In one case, the medium elevation overpressure was greater than the overpressures at the high or low elevations.

The rank order of severity of exposure (from most severe to least severe) for the crew positions is: gunner, #1, #4, #3, #5, #2, chief of section. The relative severity of exposure at 45 degrees for the XM103 and 35 degrees for the M2A2E2 for the three worst crew positions is shown below in Table 5.

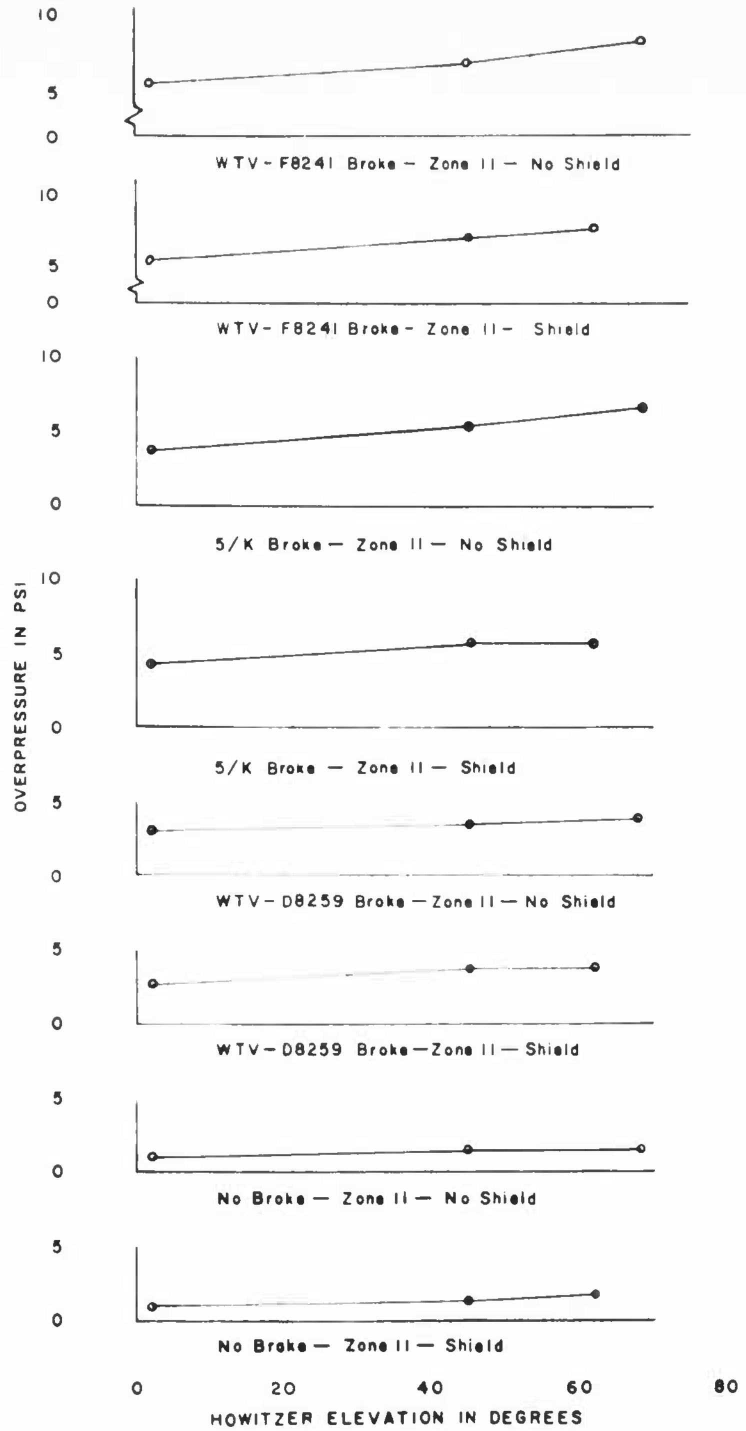


Fig. 8. GRAPHS SHOWING OVERPRESSURE INCREASE WITH HOWITZER ELEVATION AT GUNNER'S POSITION (MOST SEVERE) These graphs are also typical for severe positions #1 and #4 and the least severe position of the chief of section.

TABLE 5

Overpressures at Most Severe Crew Positions

For XM103 and M2A2E2 Howitzers at Elevations

Of 35° for M2A2E2 and 45° for XM103

		Pressures in psi		
Howitzer	Brake	Gunner	#1	#4
M2A2E2	8	7.4	6.8	4.7
XM103	WTV-F8241	7.2	6.8	5.2
XM103	5/K	5.7	4.9	3.8
XM103	WTV-D8259	3.8	3.2	2.9
XM103	No Brake	1.4	1.3	1.2

All of the comparisons shown in tables in this memorandum were based on the sign test. Table 6 shows whether or not a significant overpressure difference exists for the various brake and shield conditions. Table 7 shows comparisons between the M2A2E2 Howitzer (105mm) and the XM103 Howitzer overpressures. Table 8 shows comparisons between the overpressures for the three elevations at which the XM103 Howitzer was fired, and Table 9 shows differences due to different propelling charges.

TABLE 6

Significant Overpressure Differences

Pertaining to the XM103 Muzzle Brake and Blast Shield Conditions

(Propelling Charge Zone 11)

XM103 Brakes: WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), WTV-D8259 (Low Efficiency), N.B. (No Brake)

	2°			45°		
	WTV-F8241 vs. 5/K	5/K vs. WTV-D8259	WTV-D8259 vs. N.B.	WTV-F8241 vs. 5/K	5/K vs. WTV-D8259	WTV-D8259 vs. N.B.
No Shield	WTV-F8241 >	5/K > [a]	WTV-D8259 >	WTV-F8241 >	5/K >	WTV-D8259 >
Shield	WTV-F8241 >	5/K >	WTV-D8259 >	WTV-F8241 >	5/K >	WTV-D8259 >

	62-68°		
	WTV-F8241 vs. 5/K	5/K vs. WTV-D8259	WTV-D8259 vs. N.B.
No Shield	WTV-F8241 >	NSD[b]	WTV-D8259 >
Shield	WTV-F8241 >	5/K >	WTV-D8259 >

XM103 - Shield vs. No Shield

	2°	45°	62-68°
WTV-F8241	NSD[b]	NSD	NSD
5/K	NSD	NSD	NSD
WTV-D8259	NSD	NSD	No Shield >
No Brake	NSD	NSD	No Shield >

a > Means "greater than", e.g., 5/K > means that overpressures from the 5/K brake are significantly greater than overpressures from the WTV-D8259 brake.

b No significant difference for Zone 11 charge; 5/K > WTV-D8259 for Zone 9 and Zone 10 charges.

TABLE 7

Significant Overpressure Differences

Between the M2A2E2 and XM103 Howitzers

	M2A2E2 vs. XM103 with WTV-F8241 Brake[b]		
	1-2°	35-45°	62-70°
No Shield	NSD[a]	NSD	NSD
Shield	NSD	NSD	XM103 > [e]
	M2A2E2 vs. XM103 with 5/K Brake[c]		
	1-2°	35-45°	62-70°
No Shield	NSD	NSD	NSD
Shield	NSD	M2A2E2 >	M2A2E2 >
	M2A2E2 vs. XM103 with WTV-D8259 Brake[d]		
	1-2°	35-45°	62-70°
No Shield	M2A2E2 >	M2A2E2 >	M2A2E2 >
Shield	M2A2E2 >	M2A2E2 >	M2A2E2 >

[a] No significant difference

[b] High efficiency brake

[c] Medium efficiency brake

[d] Low efficiency brake

[e] > Means "greater than", e.g., XM103   means that overpressures from the XM103 Howitzer are significantly greater than overpressures from the M2A2E2 Howitzer.

TABLE 8

Significant Differences Between Overpressures

At Different XM103 Elevations

XM103 Brakes: WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), WTV-D8259 (Low Efficiency), N.B. (No Brake)

	2° vs. 45°			
	WTV-F8241	5/K	WTV-D8259	No Brake
No Shield	NSD[a]	$45^\circ >$ [b]	$45^\circ >$	$45^\circ >$
Shield	NSD	NSD	$45^\circ >$	$45^\circ >$
	45° vs. $62\text{-}68^\circ$			
	WTV-F8241	5/K	WTV-D8259	No Brake
No Shield	$62\text{-}68^\circ >$	NSD	$62\text{-}68^\circ >$	$62\text{-}68^\circ >$
Shield	$62\text{-}68^\circ >$	$62\text{-}68^\circ >$	$62\text{-}68^\circ >$	$62\text{-}68^\circ >$

[a] No significant difference

[b] > Means "greater than", e.g., 45° means that overpressures at 45° are significantly greater than overpressures at 2°.

TABLE 9

Significant Differences Between Overpressures

Due To Different Propelling Charges

(No Blast Shield)

Elevation	Zone 9 vs. Zone 10: WTV-F8241	Zone 9 vs. Zone 10: 5/K	Zone 9 vs. Zone 10: WTV-D8259
68°	Zone 10 > [a]	Zone 10 >	Zone 10 >

Elevation	Zone 10 vs. Zone 11: WTV-F8241	Zone 10 vs. Zone 11: 5/K	Zone 10 vs. Zone 11: WTV-D8259	Zone 10 vs. Zone 11: No Brake
2°	NSD[b]	NSD	NSD	NSD
45°	NSD	Zone 11 >	NSD	NSD
68°	NSD	NSD	Zone 11 >	c

a > Means "greater than", e.g., Zone 10 means that overpressures from the Zone 10 charge are significantly greater than overpressures from the Zone 9 charge.

b No significant difference.

c No Zone 10 and Zone 11 rounds fired at this condition.

Analysis and Discussion

Damage-Risk Criteria

Several damage-risk criteria (DRC) have been established for continuous noise, such as the noise produced by jet aircraft engines, but at present no DRC exist for impulsive noise, such as the noise produced by gunfire. The establishment of DRC of any value is not an easy assignment. It involves many hours of literature review, the collection of firsthand information about the actual problem as it occurs locally, the marshalling and correlation of all the data, the definition of the problem, and finally the experimental attack (4). When the data are analyzed, an even more difficult problem arises - who is willing to specify how much hearing loss is acceptable for another human? Any attempts to establish DRC for exposure to impulse noise must at present be based more on guesswork than on experimental evidence (5).

The foremost problem in the establishment of a DRC for exposure to impulse noise is that it is not yet known definitely what causes damage to the ear. Most blast authorities believe that peak overpressure is the "culprit", but it has not yet been proven so. However, a recent investigation (6) indicates that for guinea pigs, velocity is apparently responsible for cochlear damage. Perhaps the most desirable physical quantity on which to base a DRC would be the over-all instantaneous peak sound pressure level (SPL_p). This quantity is easily measured and readily understood, but it does not contain information about rise time, duration, and frequency. Another problem is to reach some balance among tactical requirements, economic feasibility, compensation claims, and the assurance that the soldier will be able to perform his mission.

The Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics (CHABA) is working on the establishment of an absolute damage-risk criterion for exposure to impulse noise, but until an absolute DRC is established, the Human Engineering Laboratories do not believe that personnel should be exposed to overpressures greater than 7 psi (188 db re 0.0002 microbar) when the ears are protected. This is an arbitrary figure based on the work of Murray and Reid in Australia (7). Murray and Reid used subjects with protected and unprotected ears but the limit of exposure was approximately 7 psi.

The Human Engineering Laboratories also believe that ears should be protected whenever practical from all kinds of gunfire, including small arms. These laboratories have measured temporary hearing losses up to 75 db at 2000 cps due to 160 db re 0.0002 microbar (0.3 psi) by exposing subjects without protection to 100 rounds from the M14 rifle during a 15 minute period. Murray and Reid state that in their experience pressures as low as 0.25 psi commonly caused peak hearing losses of 40 db or more after 100 or more rounds with a 0.303 rifle fired from the hip or shoulder.

Instrumentation and Measurements

One of the foremost problems of blast phenomena study is the problem of measurement. Measurement is not easy and cheap as some people think - at present it is a very expensive project. There are several sources of error to contend with in blast measurement programs. Mechanical resonances between a piezoelectric crystal and its structural support can lead to resonance phenomena and associated changes in sensitivity, phase, etc., that cannot be predicted from the resonance characteristics of the crystal itself (8). Careful design and careful dynamic calibration of the gages can minimize this problem. Weather conditions, such as dampness and high winds, often cause postponements of programs because the adverse effects upon the gages and cables result in unreliable measurements. Regular coaxial cable tends to be microphonic, often generating signals as large as those of the gage when the cable is hit by a fragment or a shock wave (2). It is necessary to use special nonmicrophonic cable at the gage end for a length of 50 to 200 feet depending upon the intensity of the blast. There are no devices which respond fast enough to follow the time course of the peak pressure of a detonation without some degree of distortion (8). In order to interpret the record, a calibration factor is necessary for both the time and pressure scales (9). The time calibration is obtained from timing marks produced on the camera film by a standard (see p. 7) driving a small gaseous-discharge lamp. The pressure calibration factor (K_a) is obtained by relating the shock velocity at the gage to the peak pressure through the use of the Rankine-Hugoniot equation (see p. 8). The Analytical Laboratory of D&PS, Aberdeen Proving Ground, Md., maintains a history of all gages used in blast measurement programs at this installation. This is done to become familiar with each and every gage in order to reduce errors in measurement and data reduction.

Future Development

According to Slade (1), the muzzle blast problem can be solved, but not by an attachment that can be screwed onto the end of a gun mounted the way guns are mounted at present. Professor Slade contends that the effective control of muzzle blast can be achieved only by conducting the gases through ducts parallel to the tube where they can be harmlessly ejected behind the gun or up over the carriage. He justifies the added superstructure, provided a sufficiently large fraction of the gas is deflected backward. The braking action of such a device would make it possible to use a light recoil system. The net gain in the weight of an assembly using such a device need not be great and conceivably could result in a saving of weight provided a reasonably small deflector is developed. Most of the ducts carrying the gases to the rear can be made light, since the controlling factor of the duct structure would be safety from fragment damage.

Recommendations

The U. S. Army Human Engineering Laboratories recommend, based on protection of auditory acuity only, the 5/K brake as the maximum efficiency brake to be considered for use with this weapon, as well as the mandatory use of earplugs. These laboratories believe that personnel should not be exposed to overpressures greater than seven psi, even with properly fitted earplugs. The Watertown blast shield provided for this program is not recommended for this weapon.

No systematic evaluation was made of other detrimental effects resulting from the use of a muzzle brake such as obscuration, flying missiles, reluctance of crew to fire the weapon, reduced field of view of sighting devices as a function of adding a shield, etc. Some of these by-products are obviously detrimental but were not evaluated.

It is also recommended that future work on the muzzle blast problem follow the recommendations of Professor James J. Slade, Jr., as described in the National Defense Research Committee Report No. A-391, "Muzzle Blast: Its Characteristics, Effects, and Control", (1946).

References

1. J. J. Slade, Jr. "Muzzle Blast: Its Characteristics, Effects, and Control" National Defense Research Committee Report No. A-391, (1946).

2. Office of the Chief of Ordnance, "Airblast Pressure Measurement - Electronic" Ordnance Proof Manual 80-12, April 1959.

3. Sidney Siegel "The Case of Two Related Samples" in Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill Book Co., Inc., New York (1956).

4. W. I. B. Beveridge "The Art of Sciencific Investigation", The Modern Library, Random House, New York (1957).

5. W. D. Ward, W. Selters, and A. Glorig "Exploratory Studies on Temporary Threshold Shift from Impulses", J. Acoust. Soc. Am., Vol. 33: 781 (1961).

6. Personal Communication from D. H. Eldredge, Armed Forces - National Research Council Committee on Hearing and Bio-Acoustics (1962).

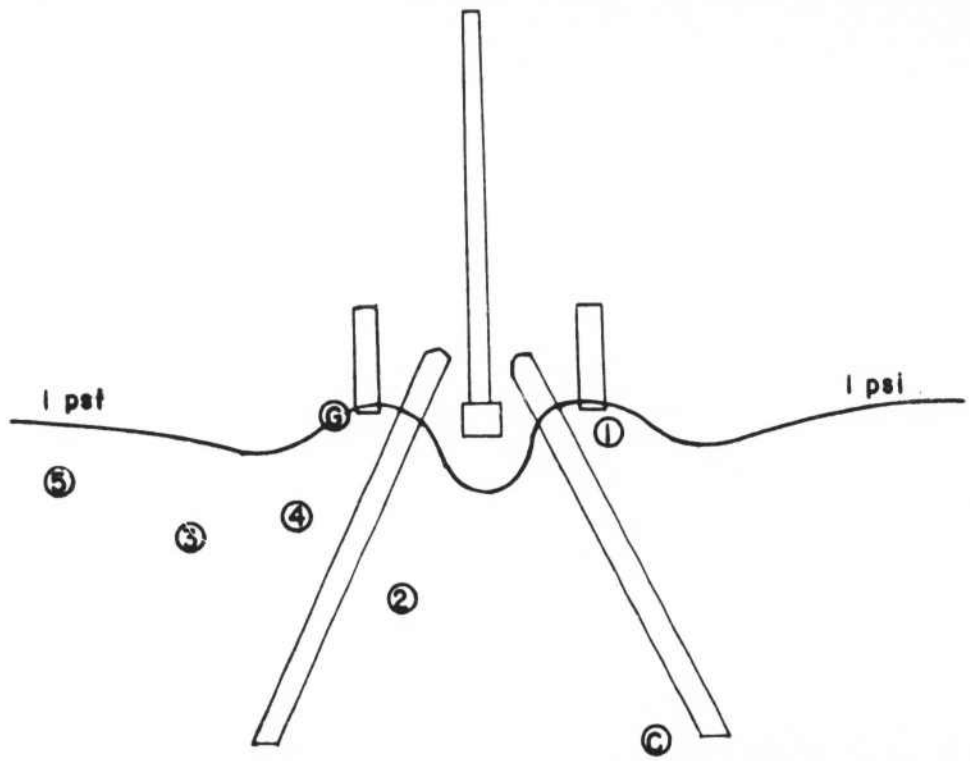
7. N. E. Murray and G. Reid "Experimental Observations on the Aural Effects of Gunblast", Med. J. of Australia, May 1946.

8. D. H. Eldredge "The Effects of Blast Phenomena on Man: A Critical Review", CHABA Report No. 3, June 1955.

9. B. F. Armendt, R. Smith and R. C. Wise "The Initial Decay of Pressure Behind a Shock Front: Comparison of Experimental and Calculated Results", Ballistic Research Laboratories Memorandum Report No. 997, Aberdeen Proving Ground, Maryland, April 1956.

Appendix

The following figures show isobars, or constant overpressure contours, for the various conditions of howitzer elevation, propelling charge, muzzle brake, and blast shield. The crew positions are shown in the lettered and numbered circles. C is the chief of section position and G is the gunner's position. The solid lines indicate measured overpressures, and the dashed lines indicate estimated overpressures. The data were computed by the Analytical Laboratory, D&PS, and the isobars were drawn by the Acoustical Research Branch, Human Engineering Laboratories, Aberdeen Proving Ground, Maryland.

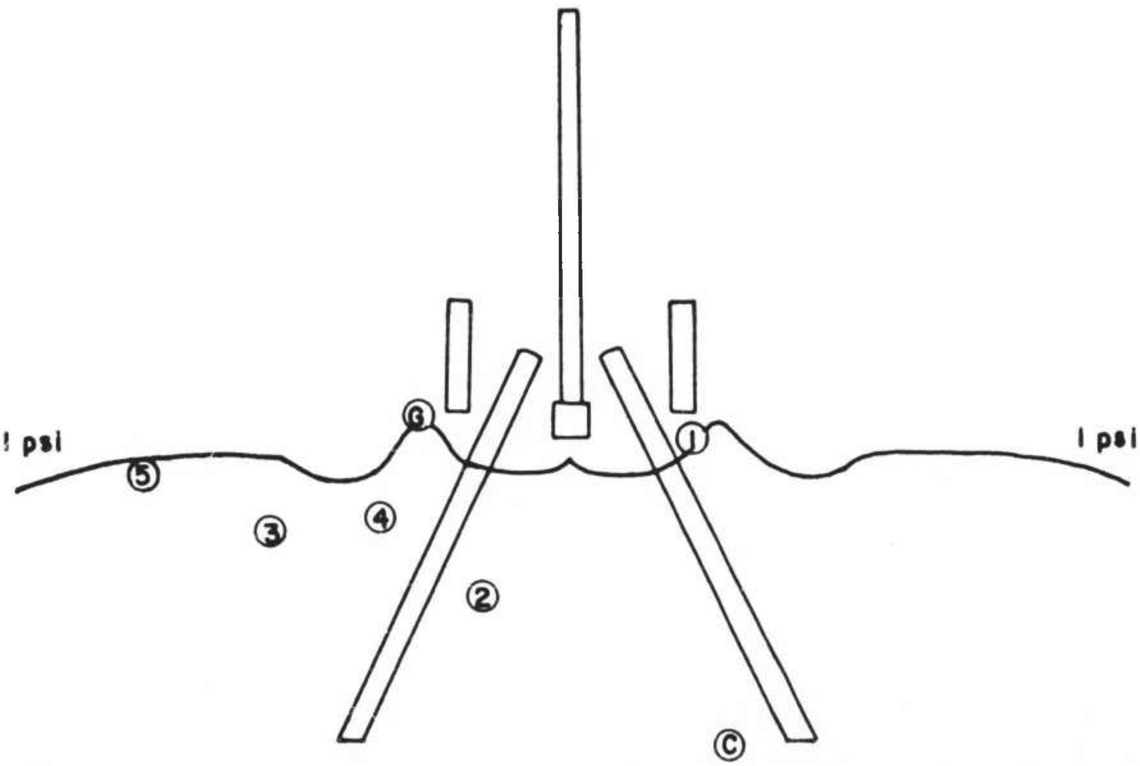


No Blast Shield

No Brake

Zone 10 - 85%

Elevation 34 - 37 mils

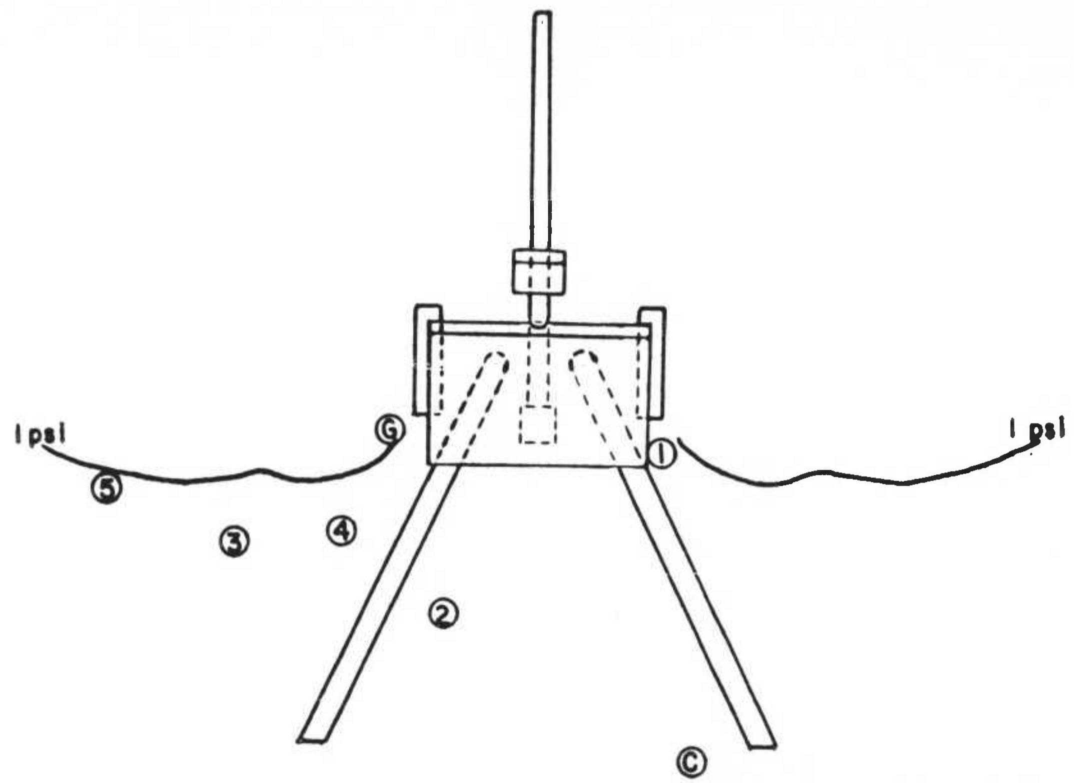


No Blast Shield

No Brake

Zone 11 - 100 %

Elevation 34-37 mils

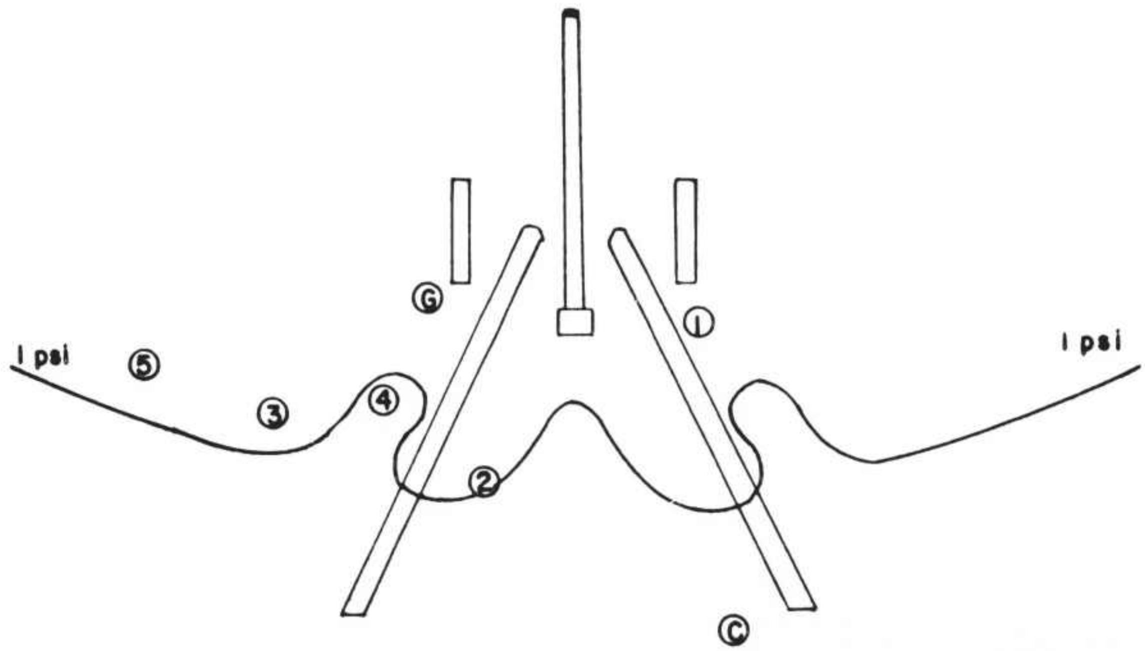


With Blast Shield

No Brake

Zone II - 100%

Elevation 40 mils

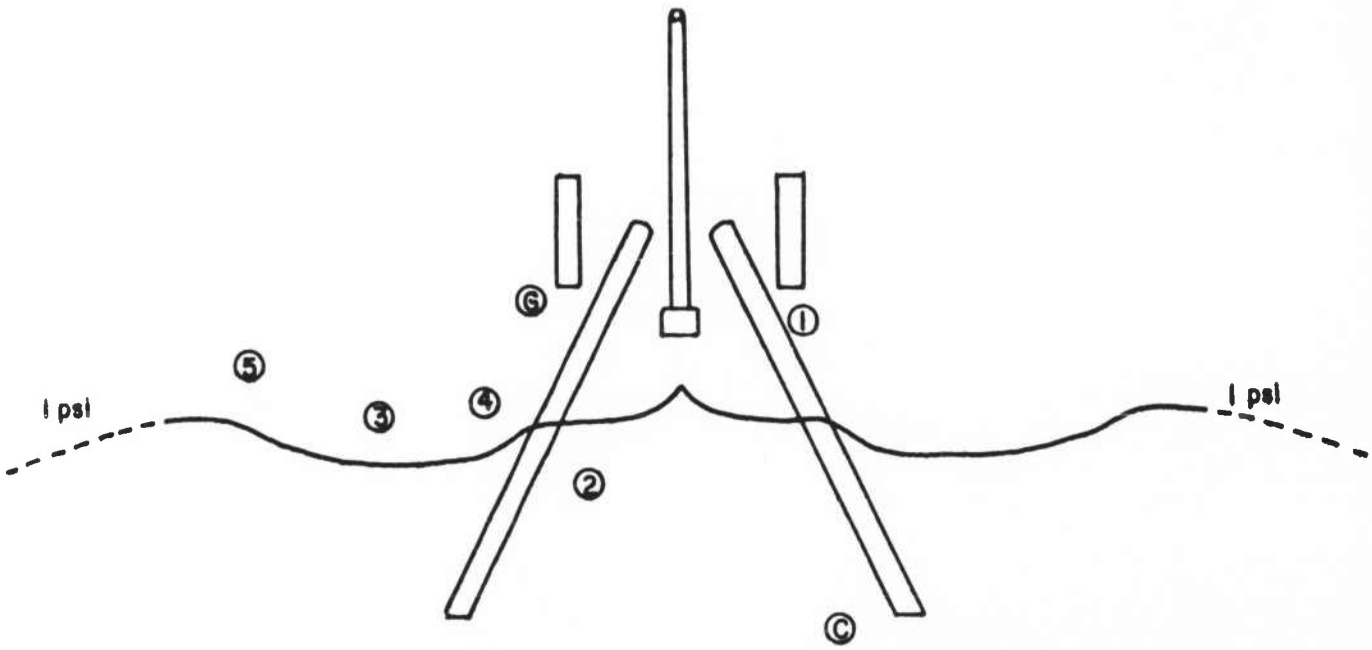


No Blast Shield

No Brake

Zone 10 - 85%

Elevation 800 mils

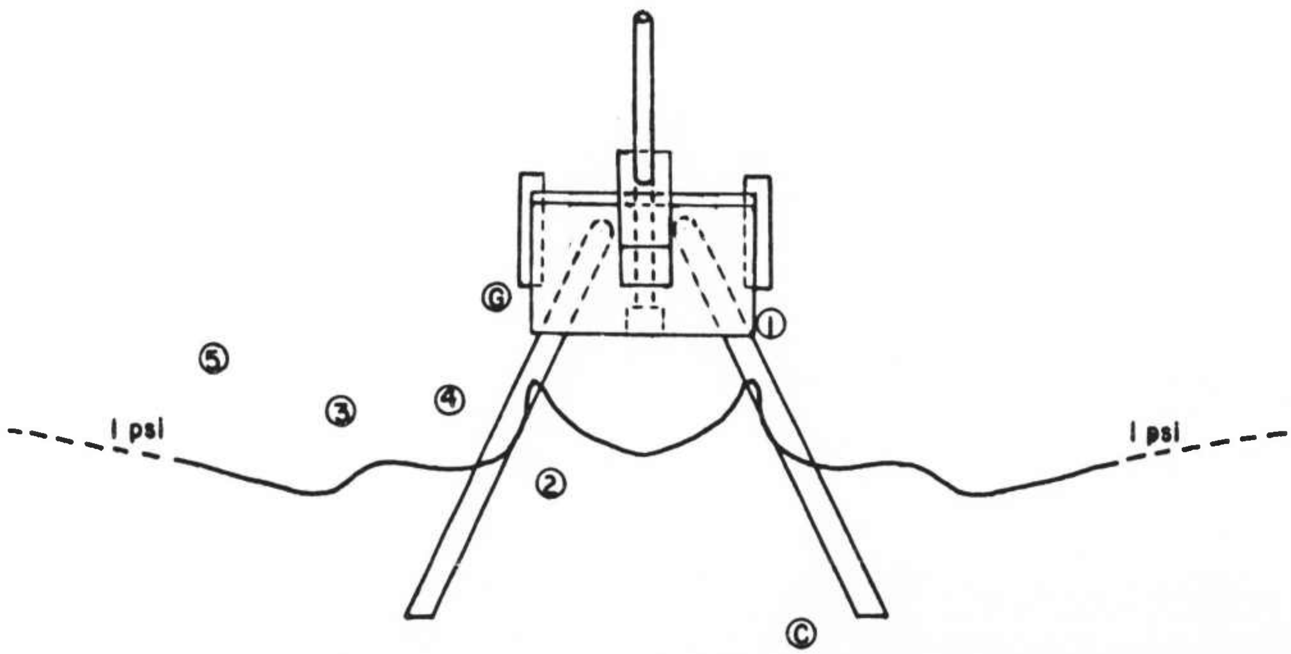


No Blast Shield

No Brake

Zone II - 100%

Elevation 800 mils

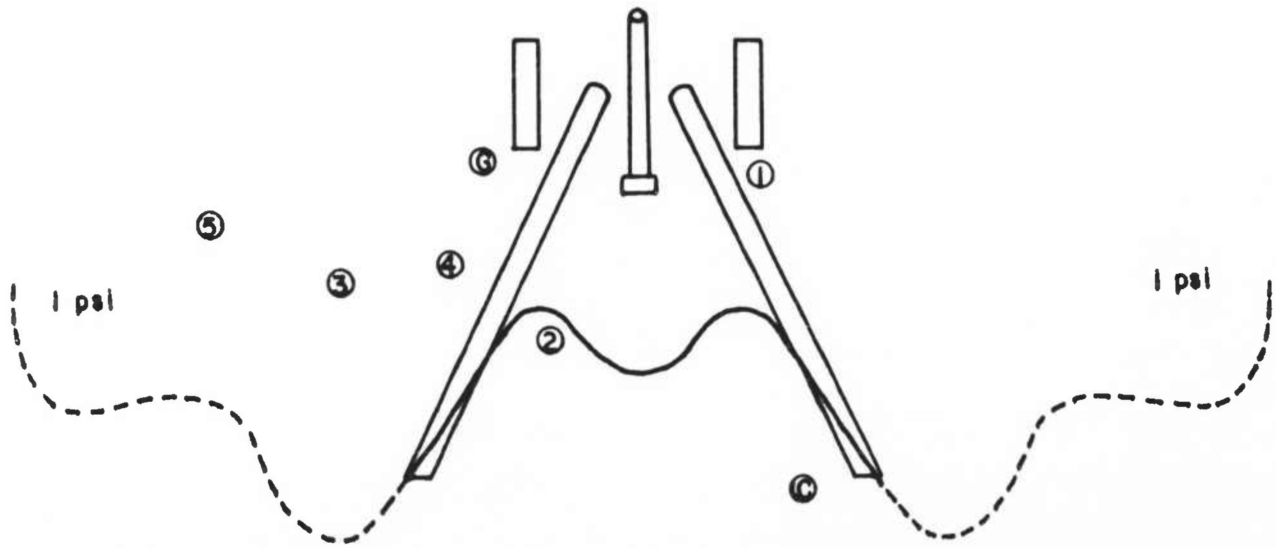


With Blast Shield

No Brake

Zone II - 100%

Elevation 800 mils.

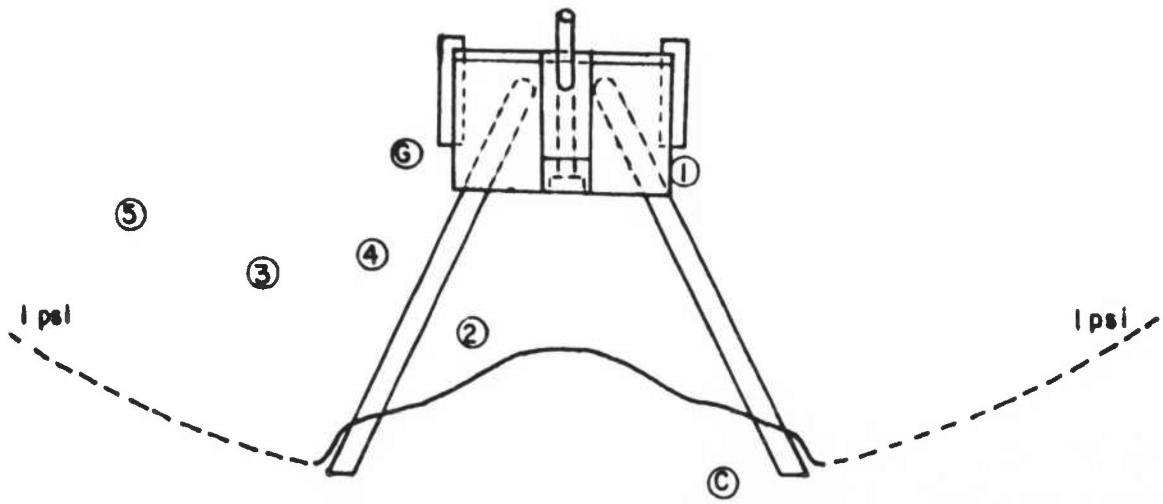


No Blast Shield

No Brake

Zone II - 100%

Elevation 1200 mils

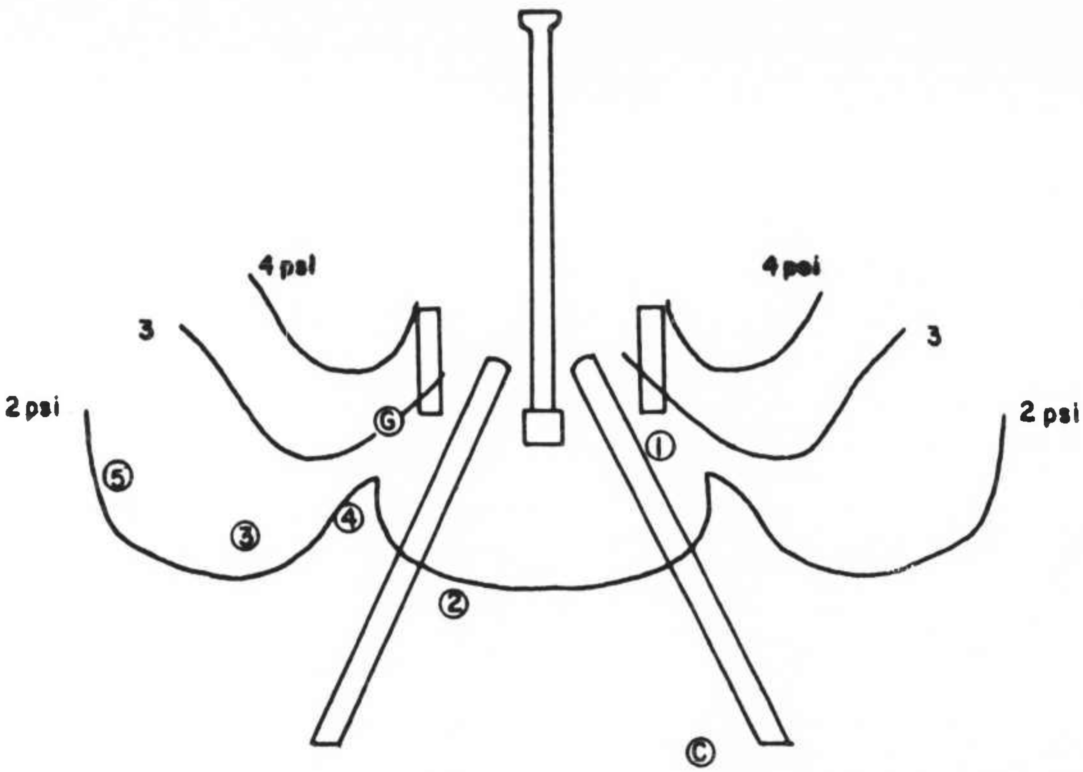


With Blast Shield

No Brake

Zone II - 100 %

Elevation 1150 mils

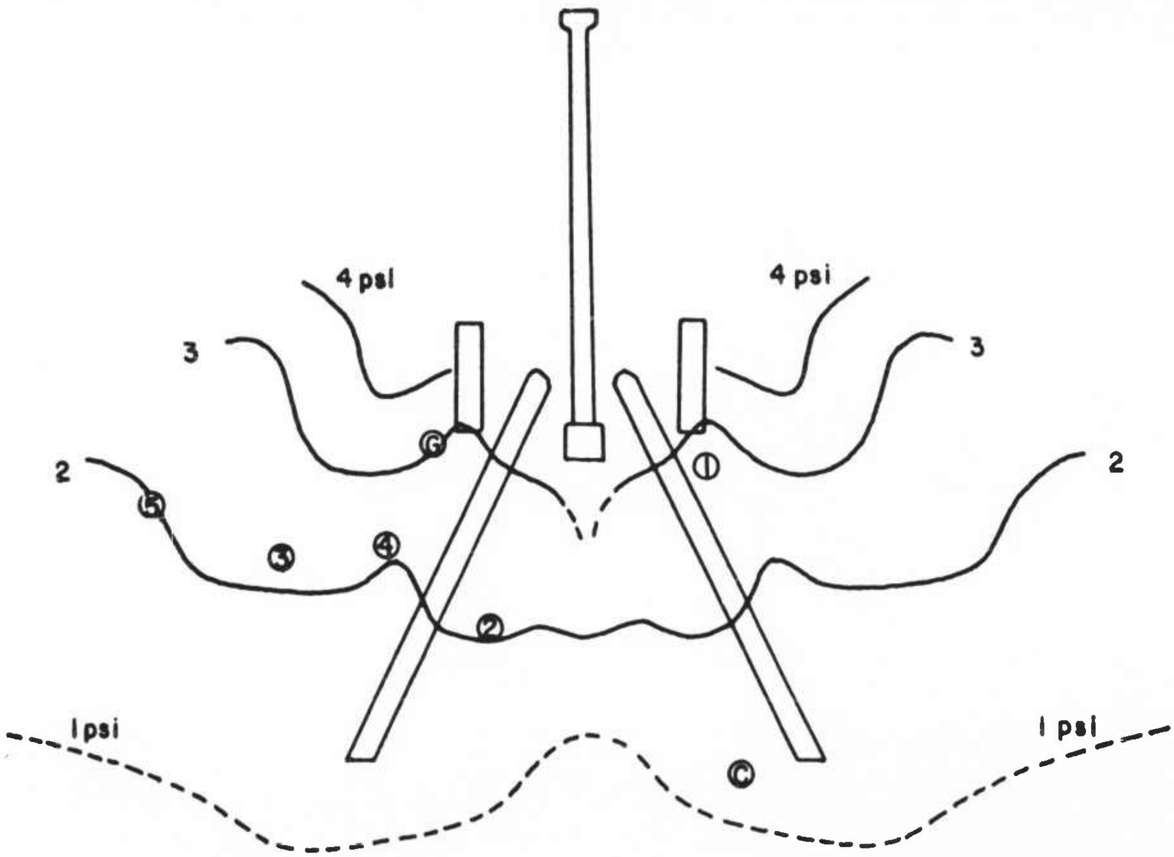


No Blast Shield

Type WTV-D8259 Brake

Zone 10 - 85 %

Elevation 34 mils

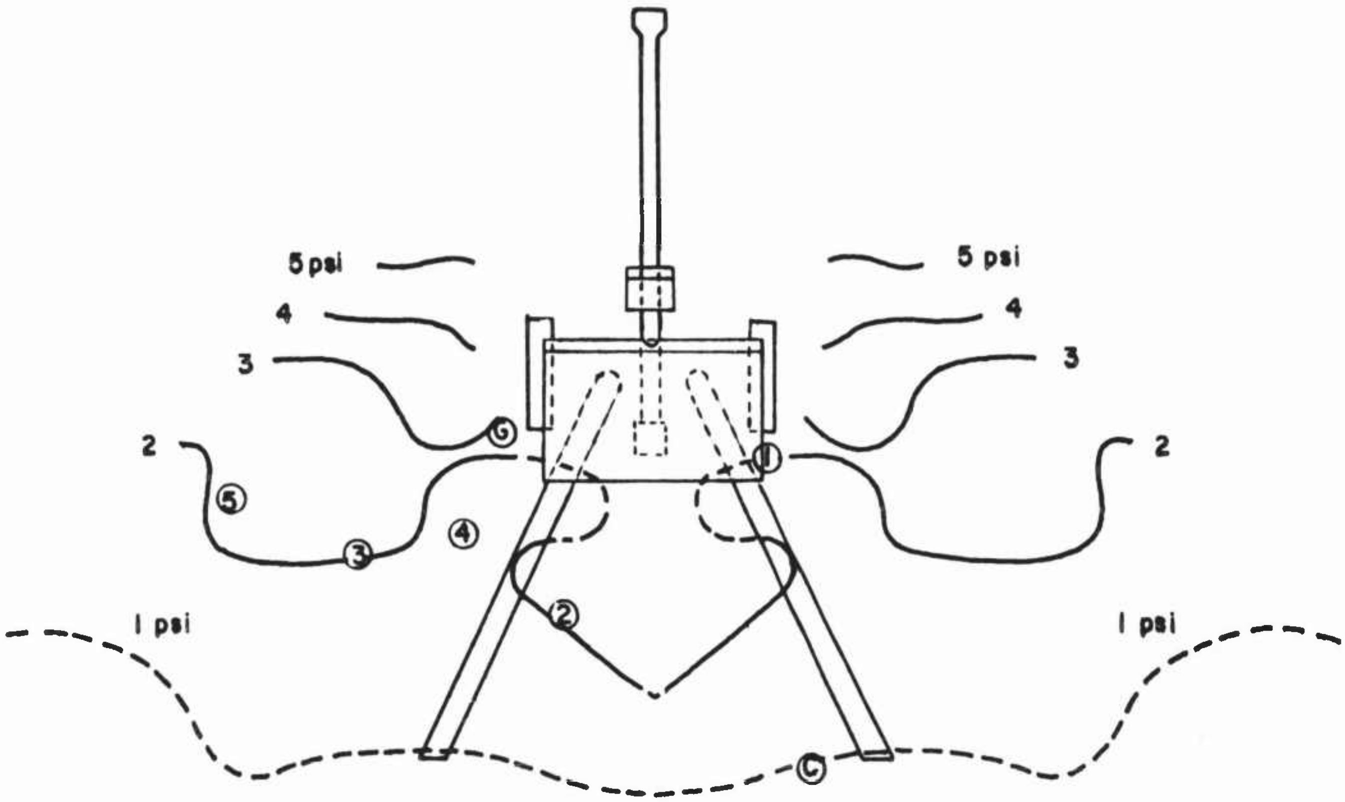


No Blast Shield

Type WTV-D8259 Brake

Zone II - 100%

Elevation 34 mils

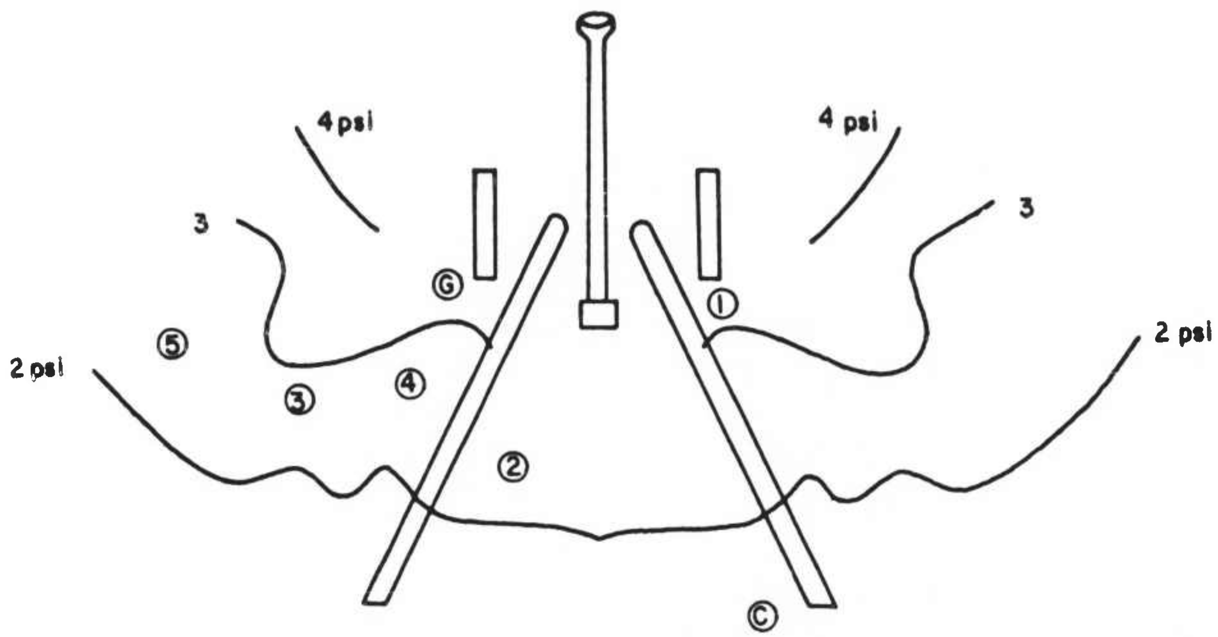


With Blast Shield

Type WTV-D8259

Zone II - 100%

Elevation 40 mils

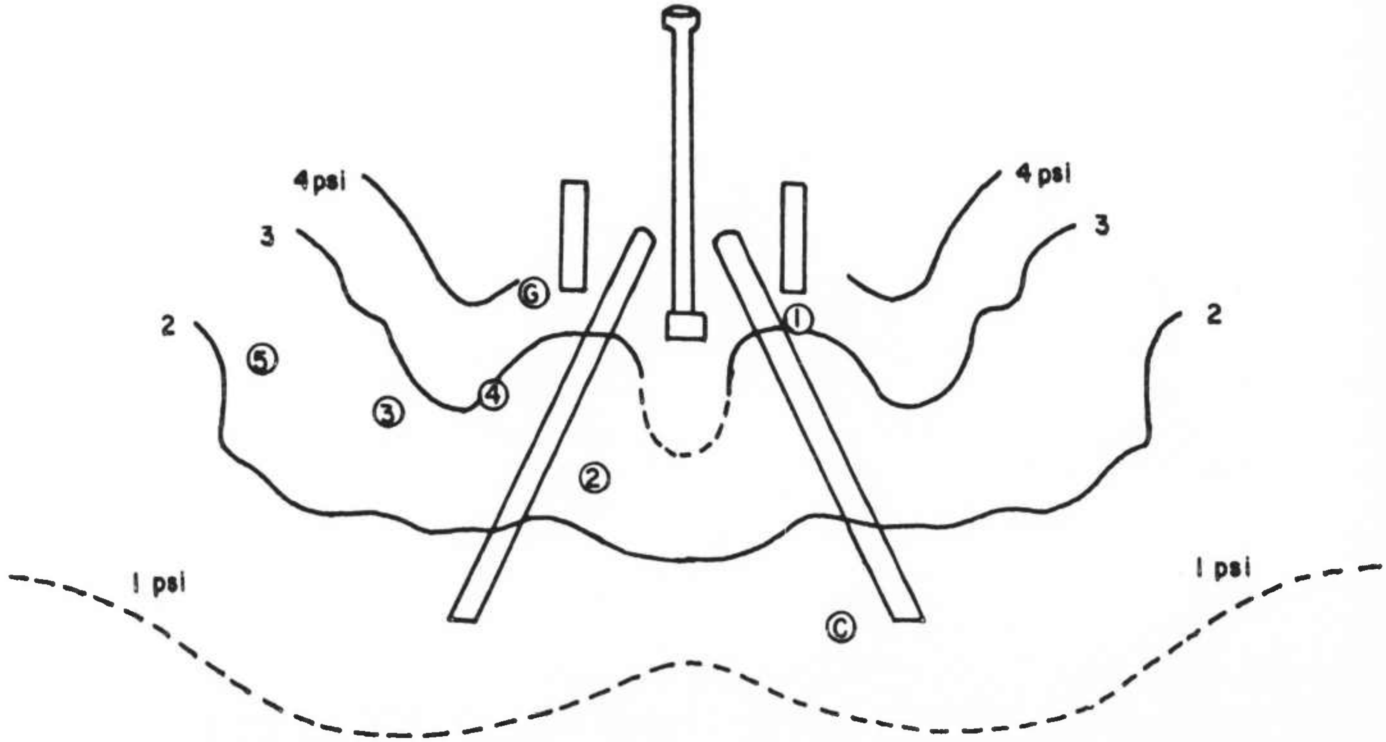


No Blast Shield

Type WTV-D8259 Brake

Zone 10 - 85 %

Elevation 800 mils

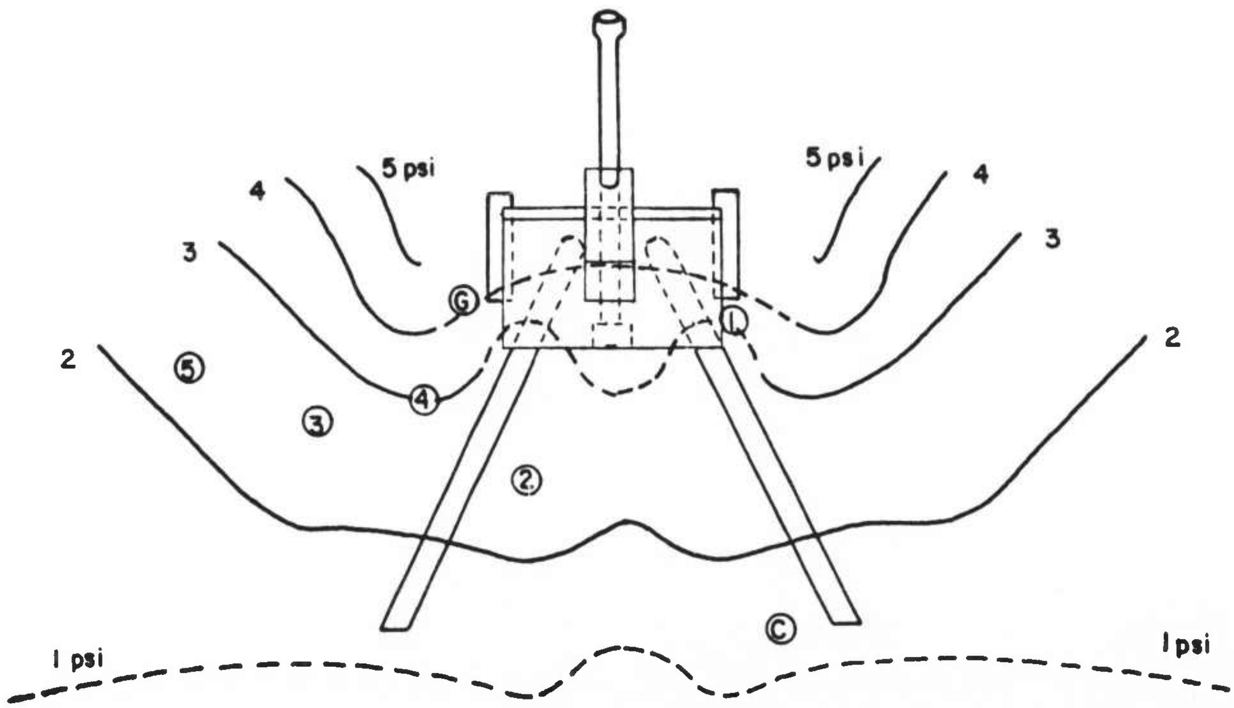


No Blast Shield

Type WTV-D8259 Brake

Zone 11 - 100%

Elevation 800 mils

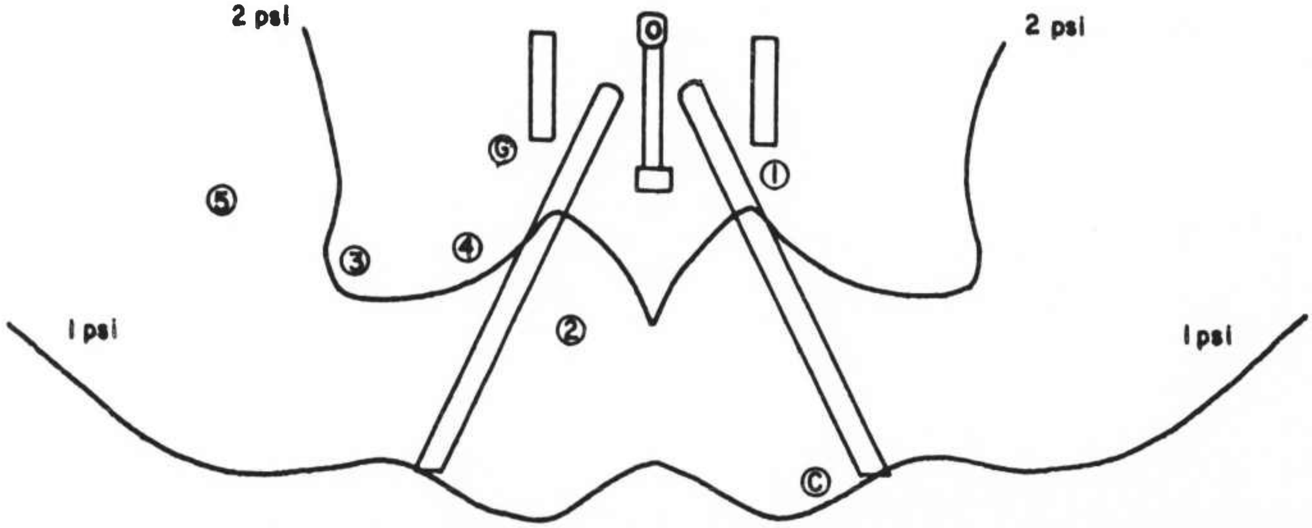


With Blast Shield

Type WTV-D8259

Zone II - 100%

Elevation 800 mils

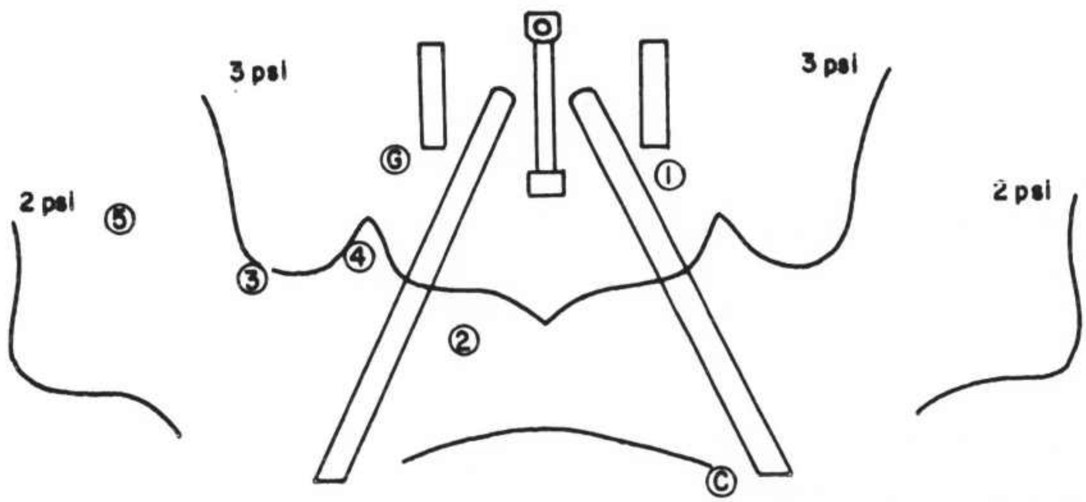


No Blast Shield

Type WTV-D8259 Brake

Zone 9 - 50%

Elevation 1200 mils

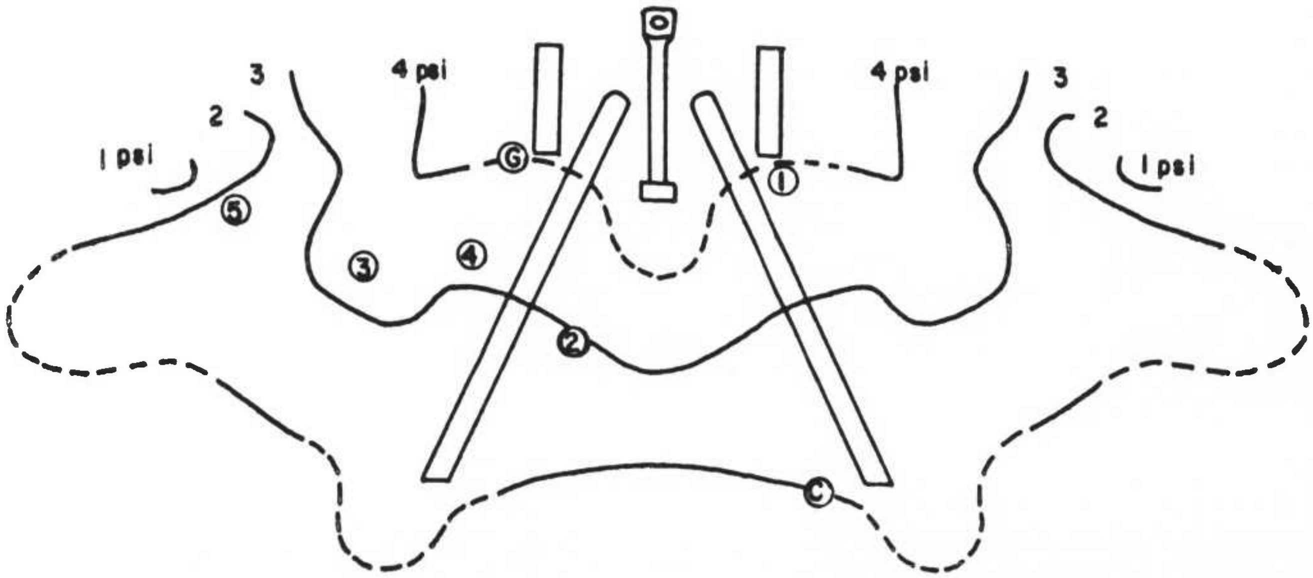


No Blast Shield

Type WTV - D8259 Brake

Zone 10 - 85 %

Elevation 1200 mils

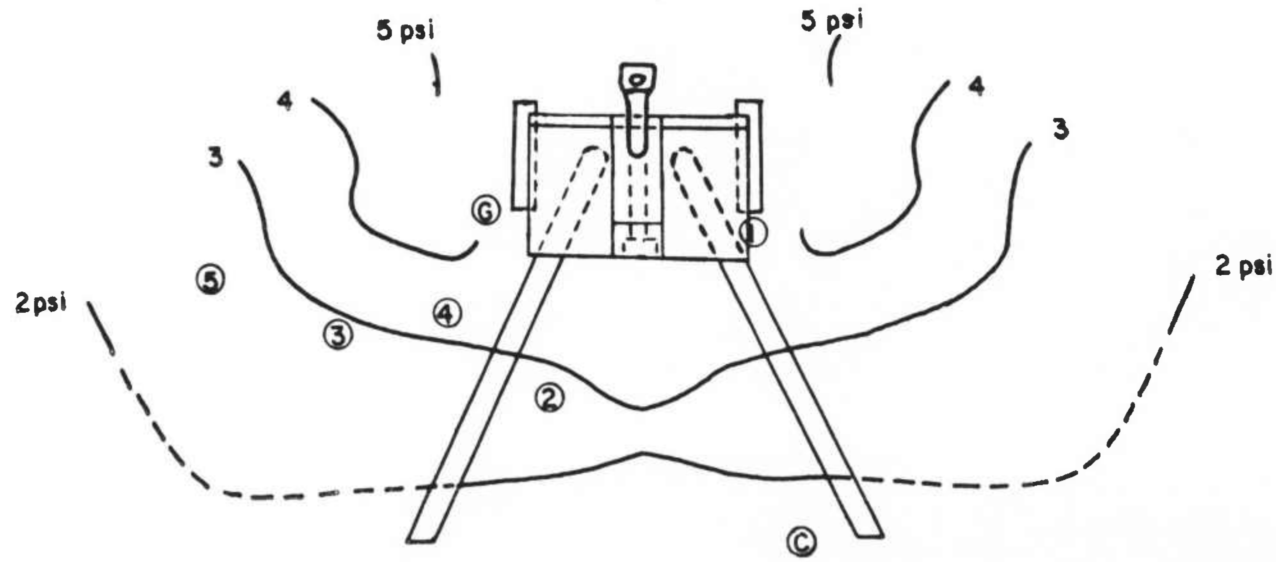


No Blast Shield

Type WTV-D8259 Brake

Zone II - 100%

Elevation 1200 mils

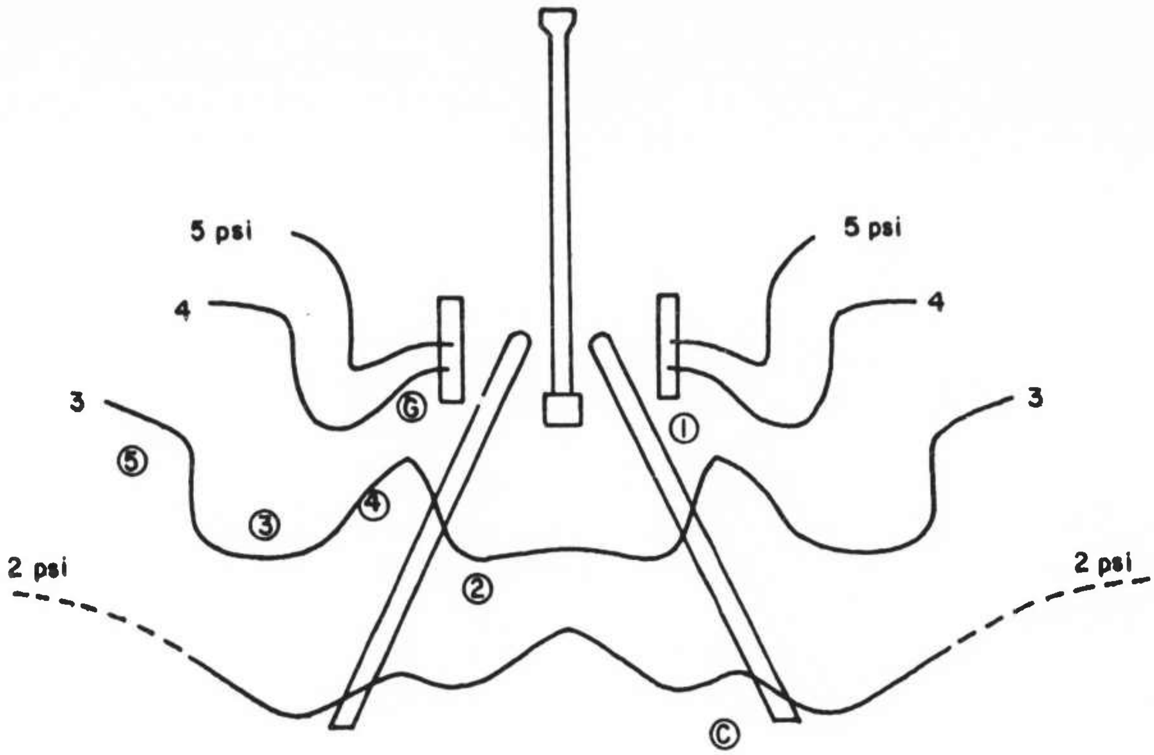


With Blast Shield

Type WTV-D8259

Zone II - 100%

Elevation 1100 mils

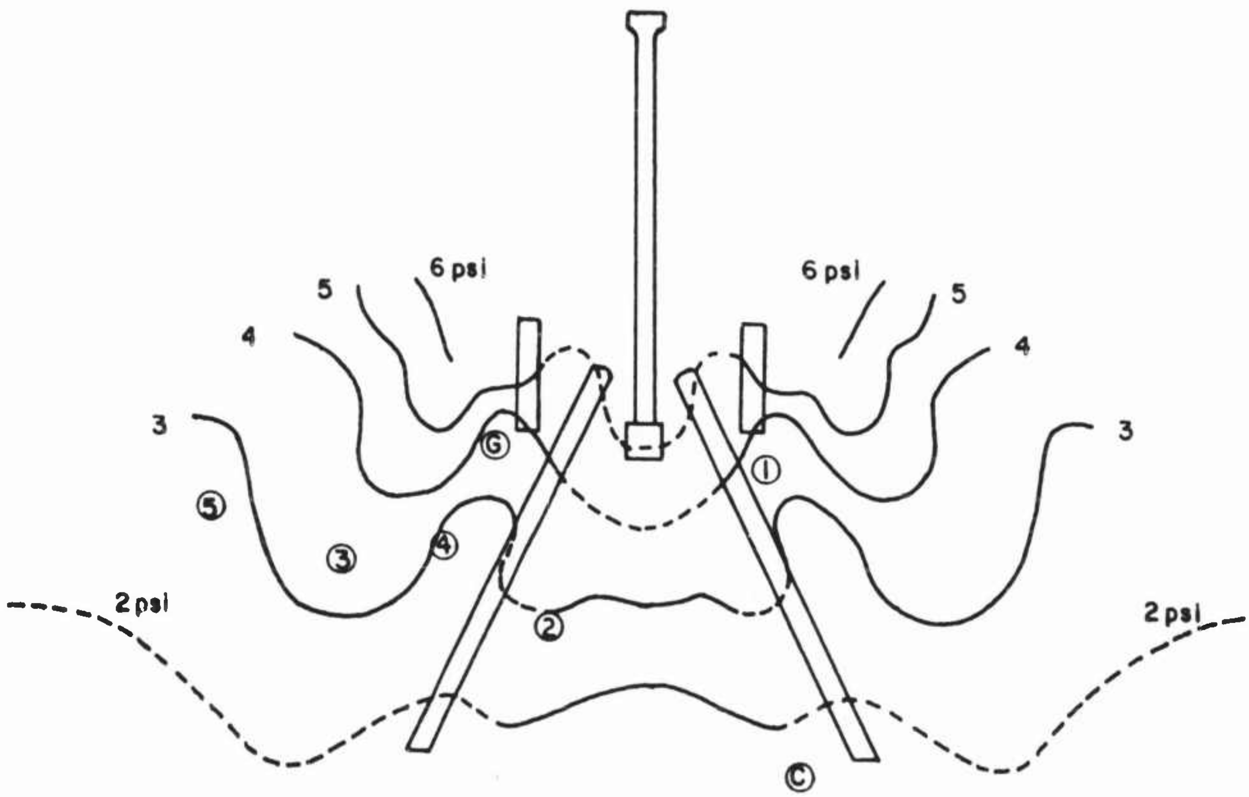


No Blast Shield

Type 5/K Brake

Zone 10 - 85 %

Elevation 34 - 37 mils

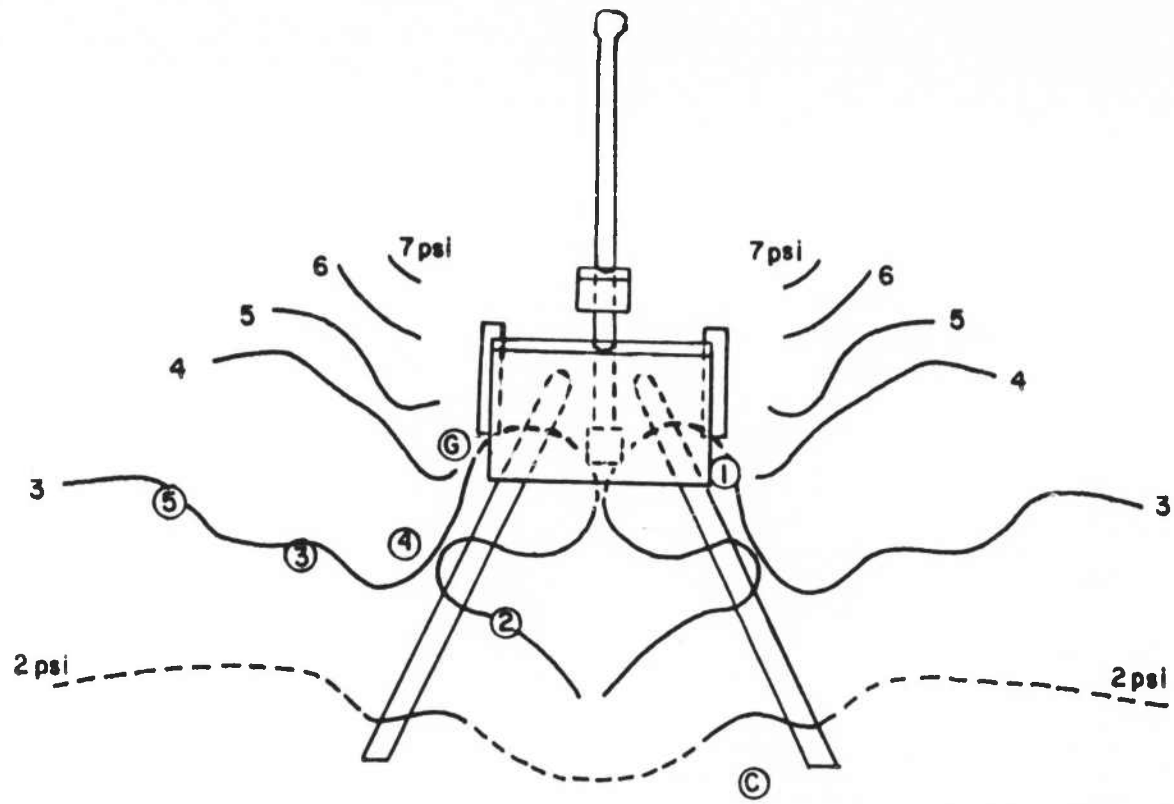


No Blast Shield

Type 5/K Brake

Zone II - 100%

Elevation 34 - 37 mils

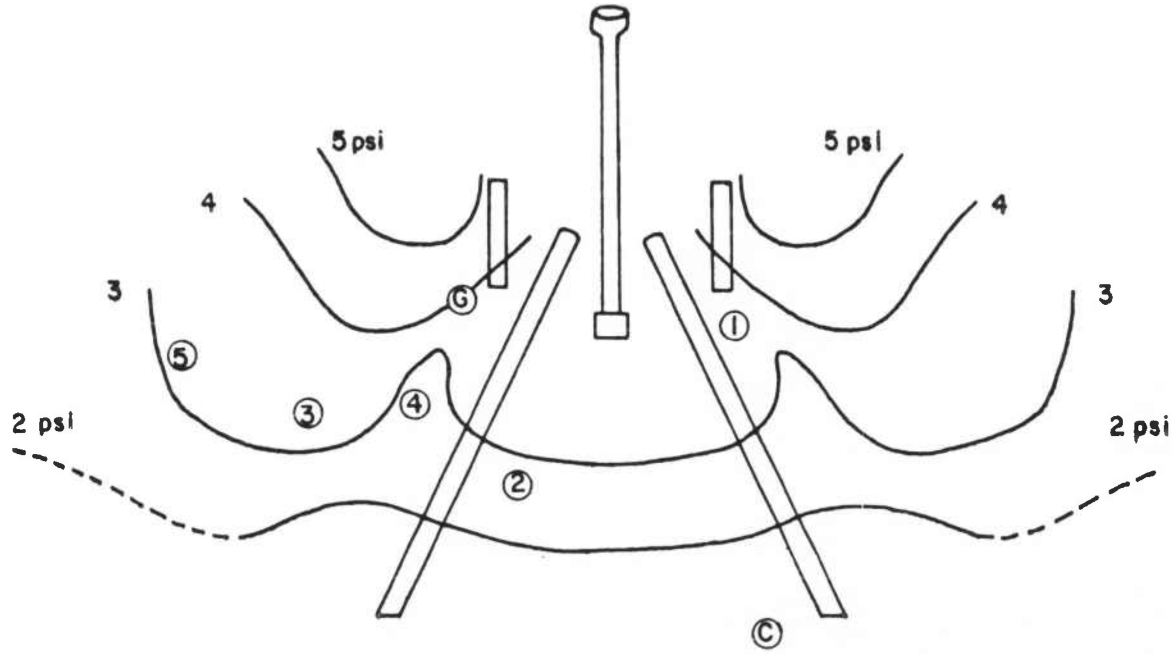


With Blast Shield

Type 5/K Brake

Zone II - 100 %

Elevation 40 mils



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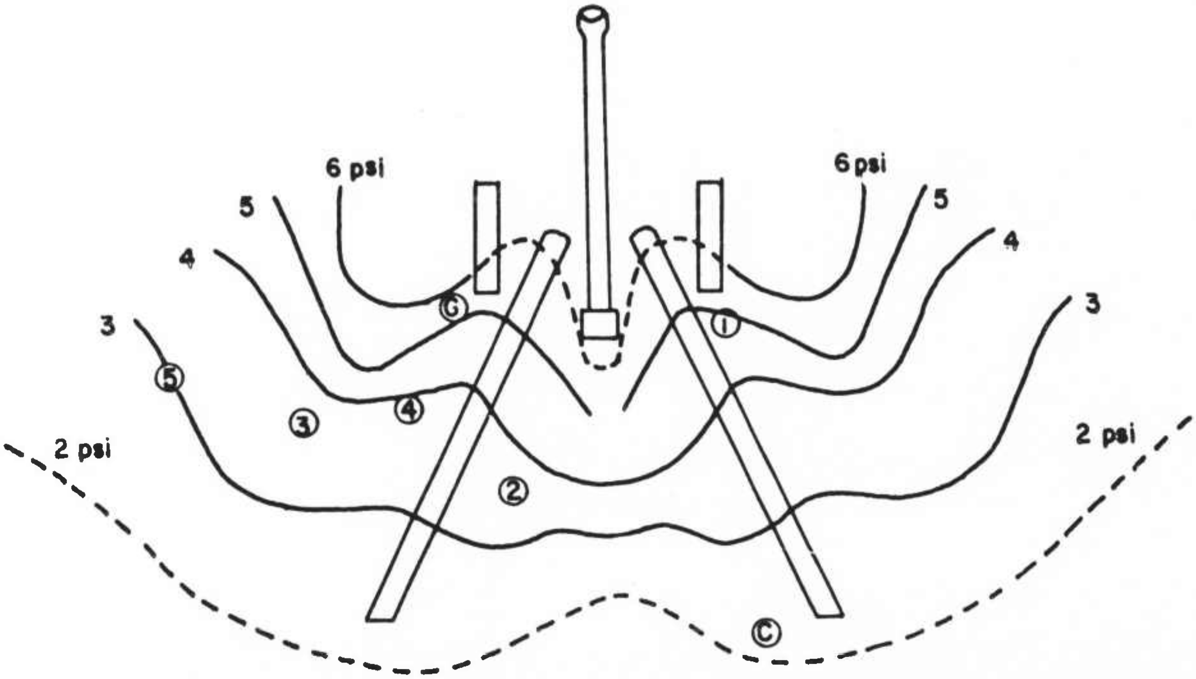
Type 5/K Brake

Zone 10 - 85 %

Elevation 800 mils



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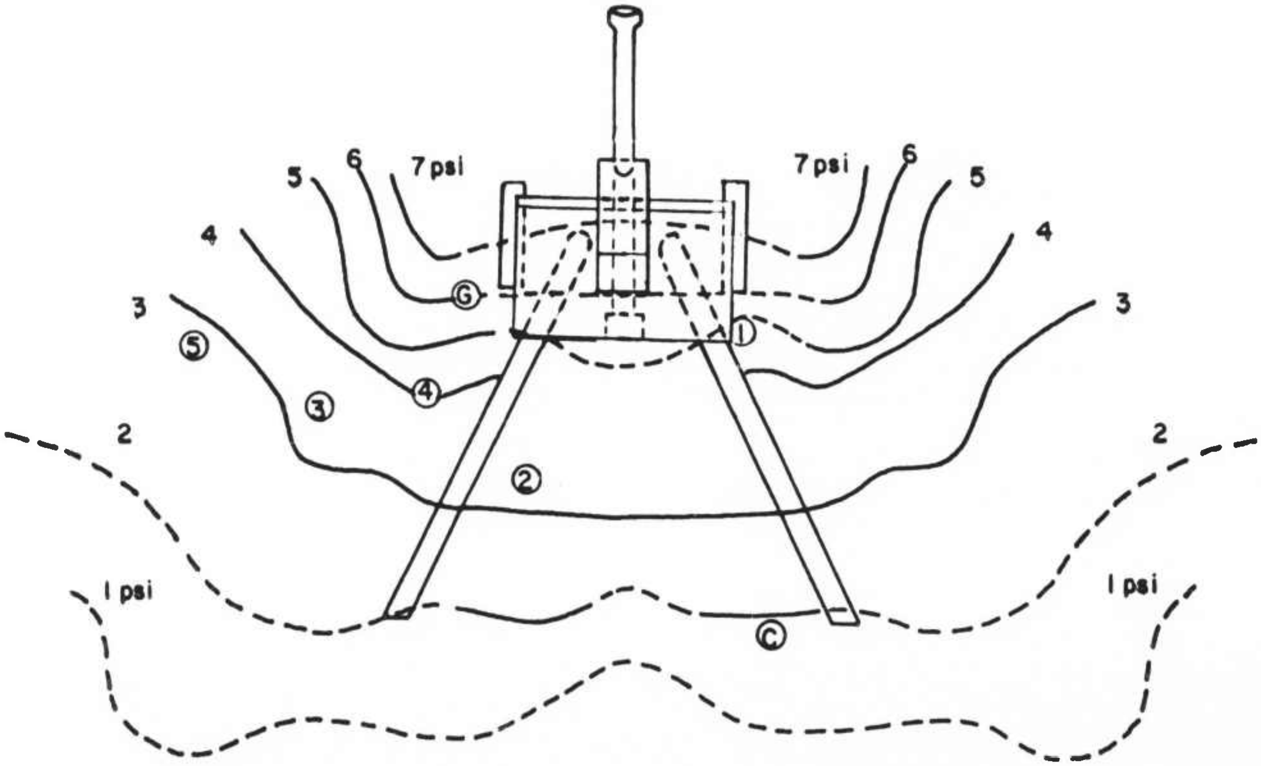
Type 5/K Brake

Zone II - 100%

Elevation 800 mils

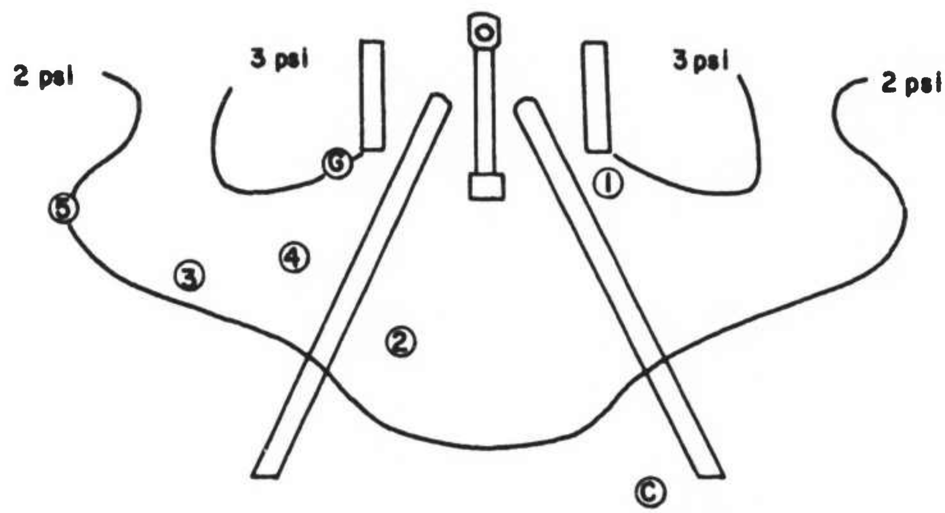


With Blast Shield

Type 5/K Brake

Zone II - 100%

Elevation 800 mils

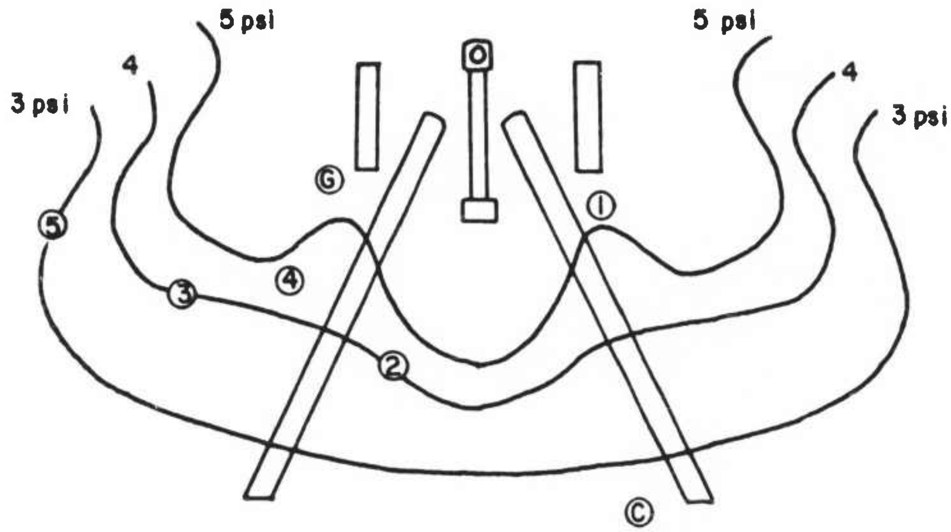


No Blast Shield

Type 5/K Brake

Zone 9 - 50 %

Elevation 1200 mils

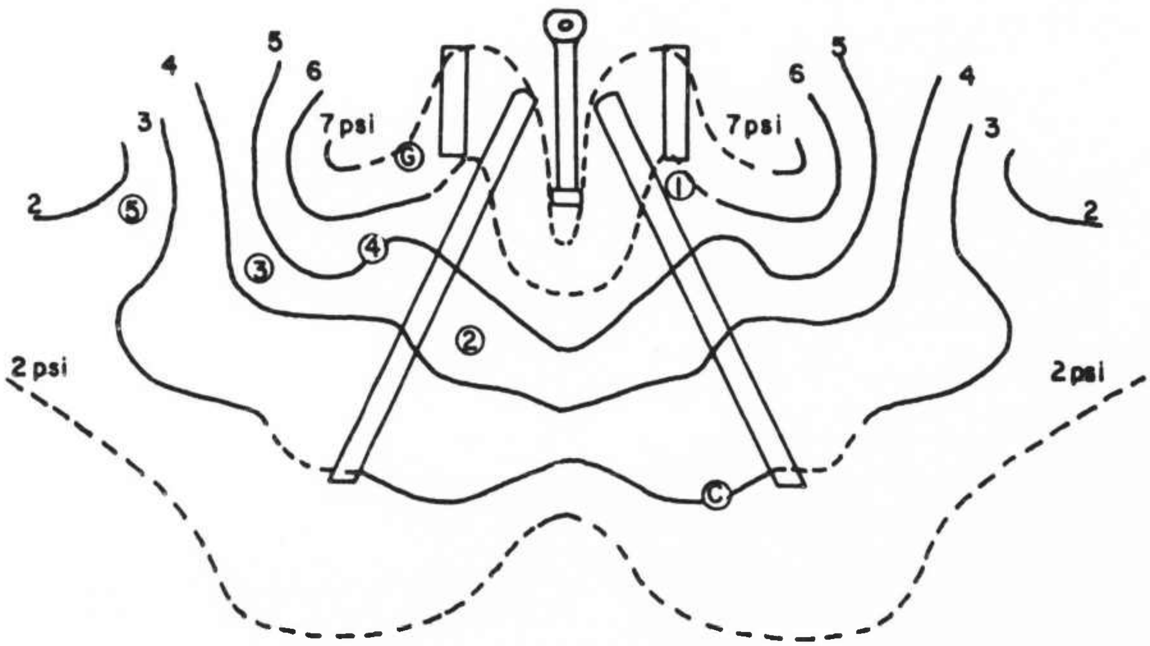


No Blast Shield

Type 5/K Brake

Zone 10 - 85%

Elevation 1200 mils



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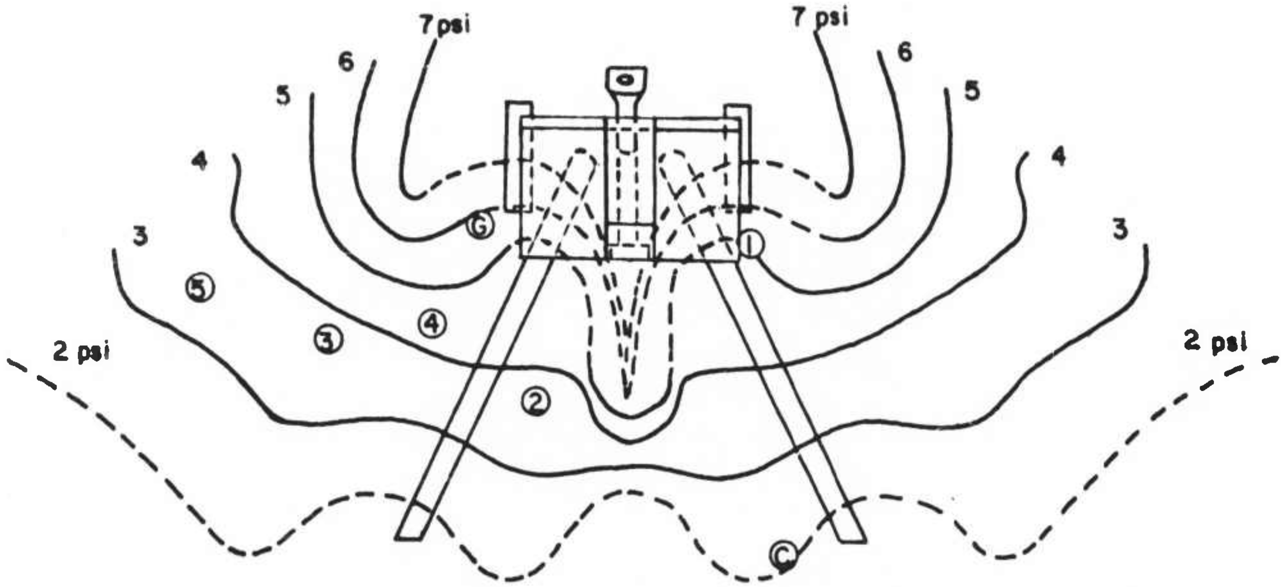
Type 5/K Brake

Zone II - 100 %

Elevation 1200 mils

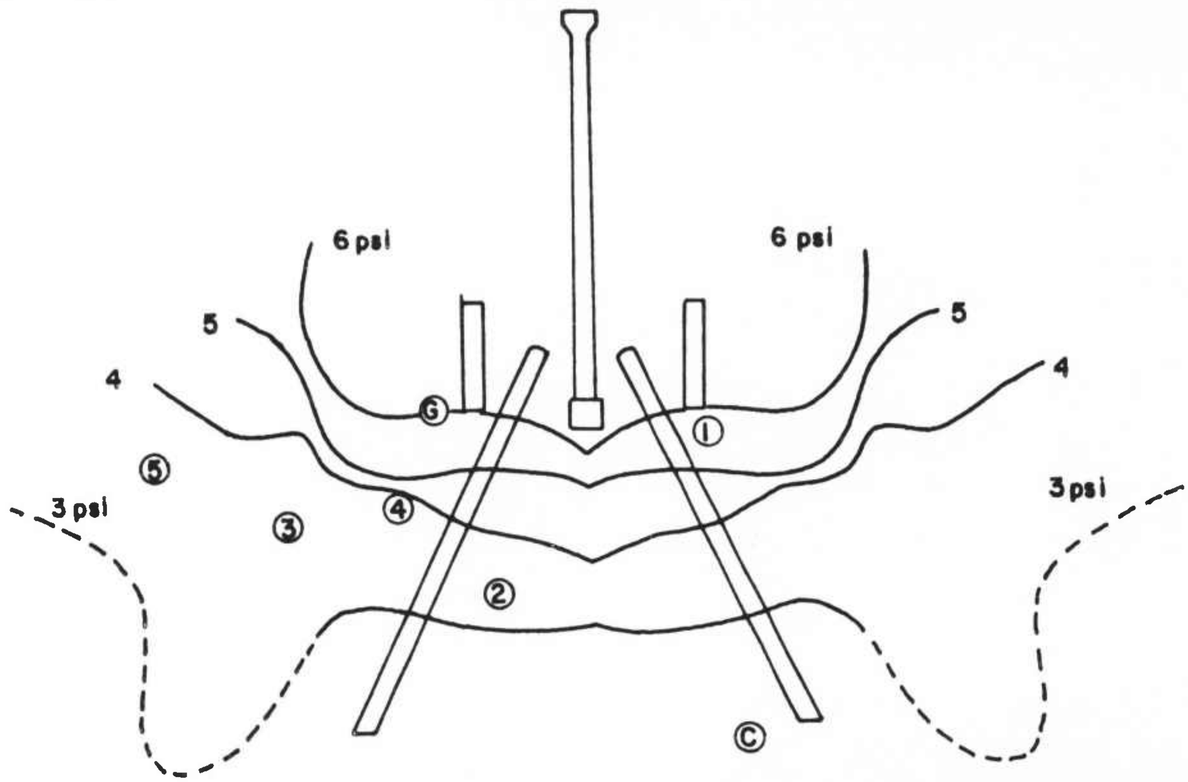


With Blast Shield

Type 5/K Brake

Zone II - 100%

Elevation 1100 mils

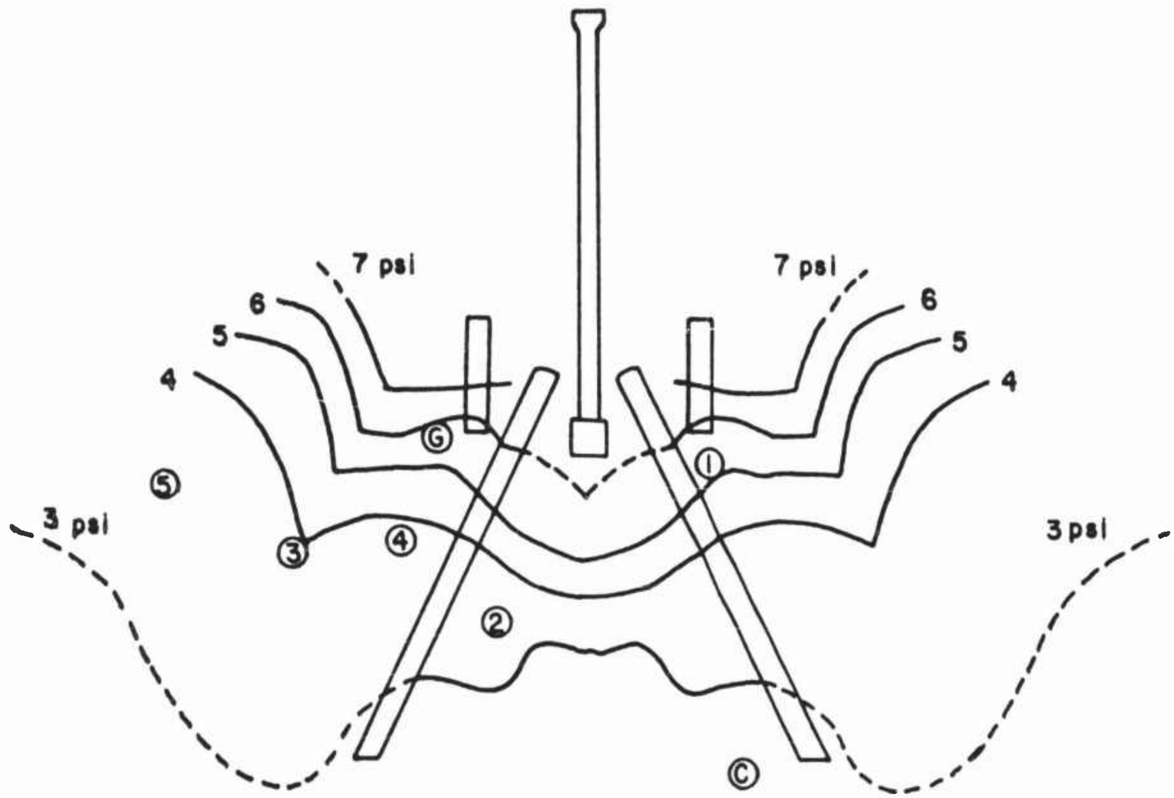


No Blast Shield

Type WTV-F8241 Brake

Zone 10 - 85%

Elevation 34 - 37 mils

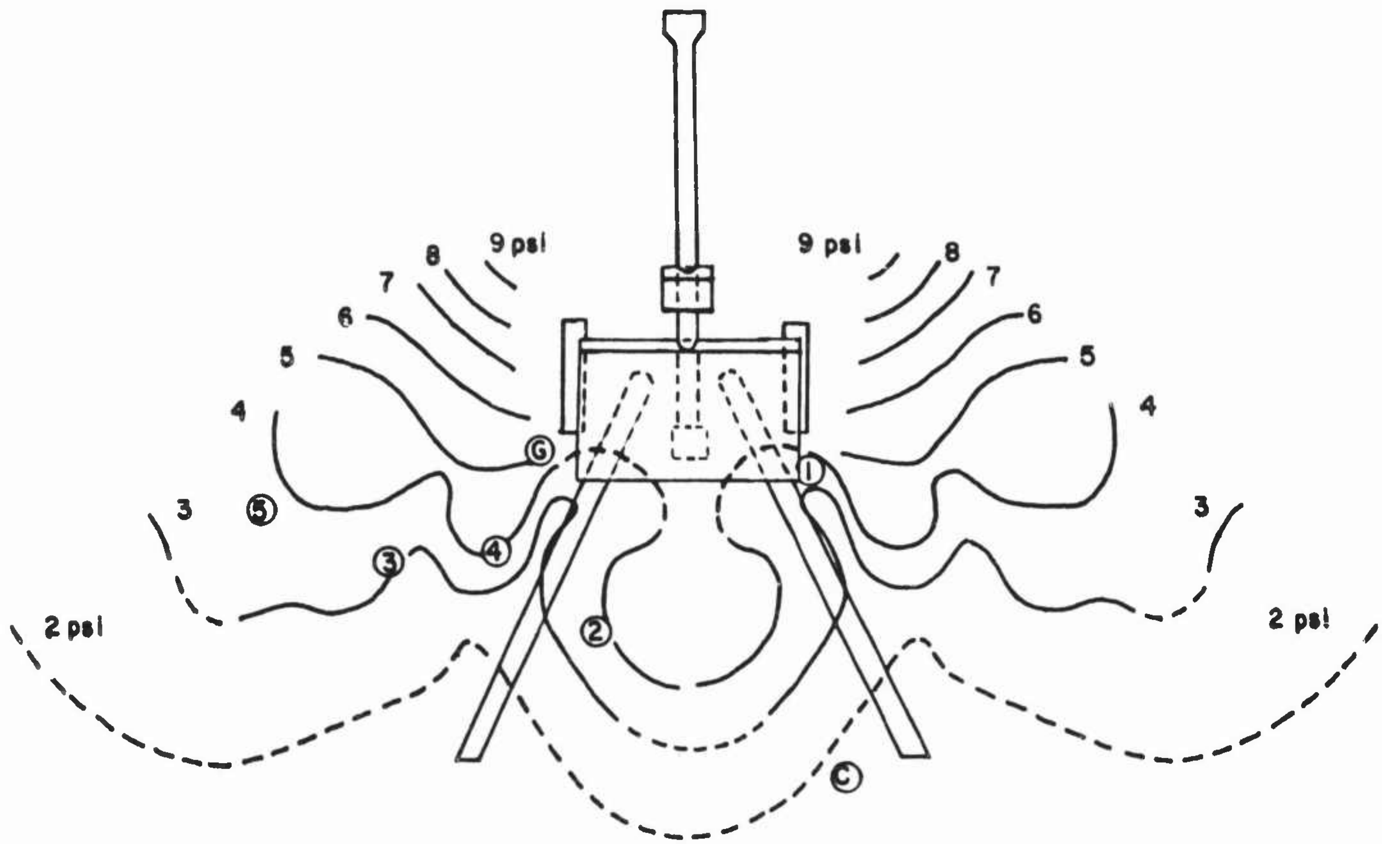


No Blast Shield

Type WTV-F8241 Brake

Zone II - 100 %

Elevation 34 - 37 mils

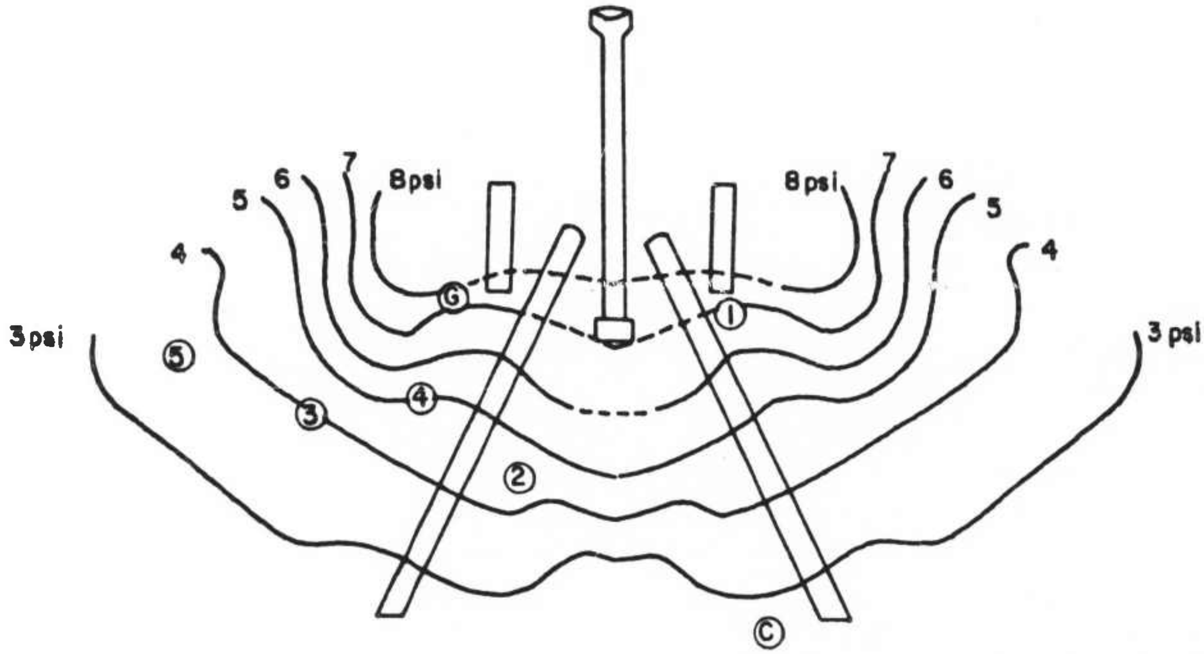


With Blast Shield

Type WTV-F8241 Brake

Zone II - 100 %

Elevation 40 mils



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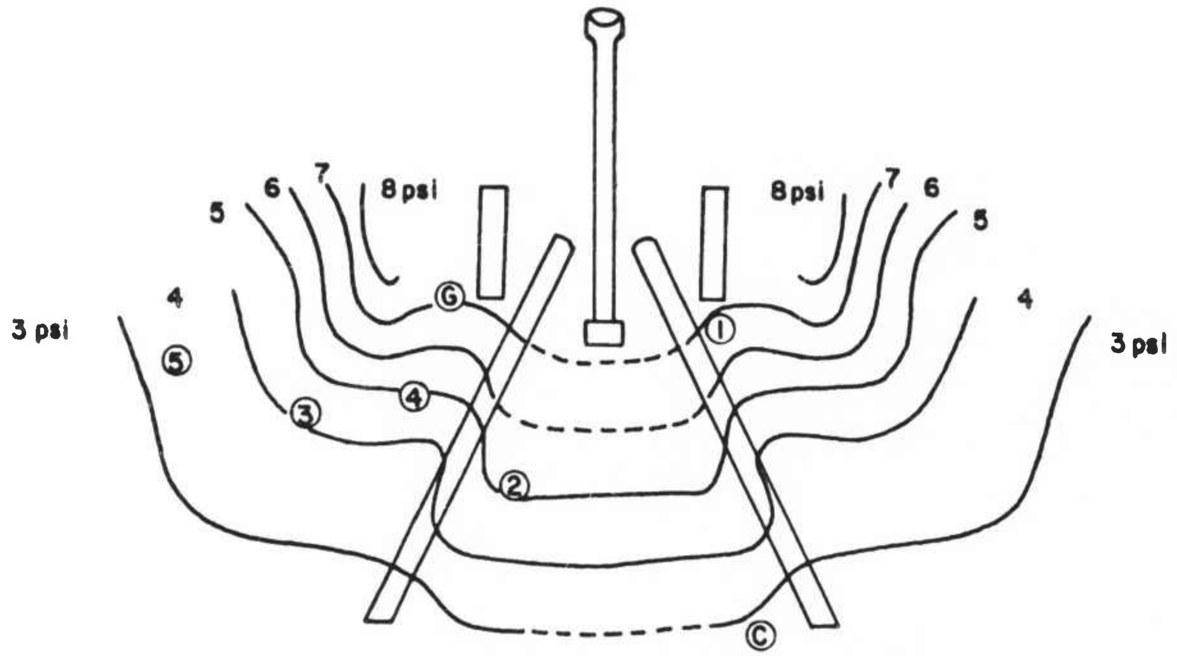
Type WTV-F8241 Brake

Zone 10 - 85 %

Elevation 800 mils

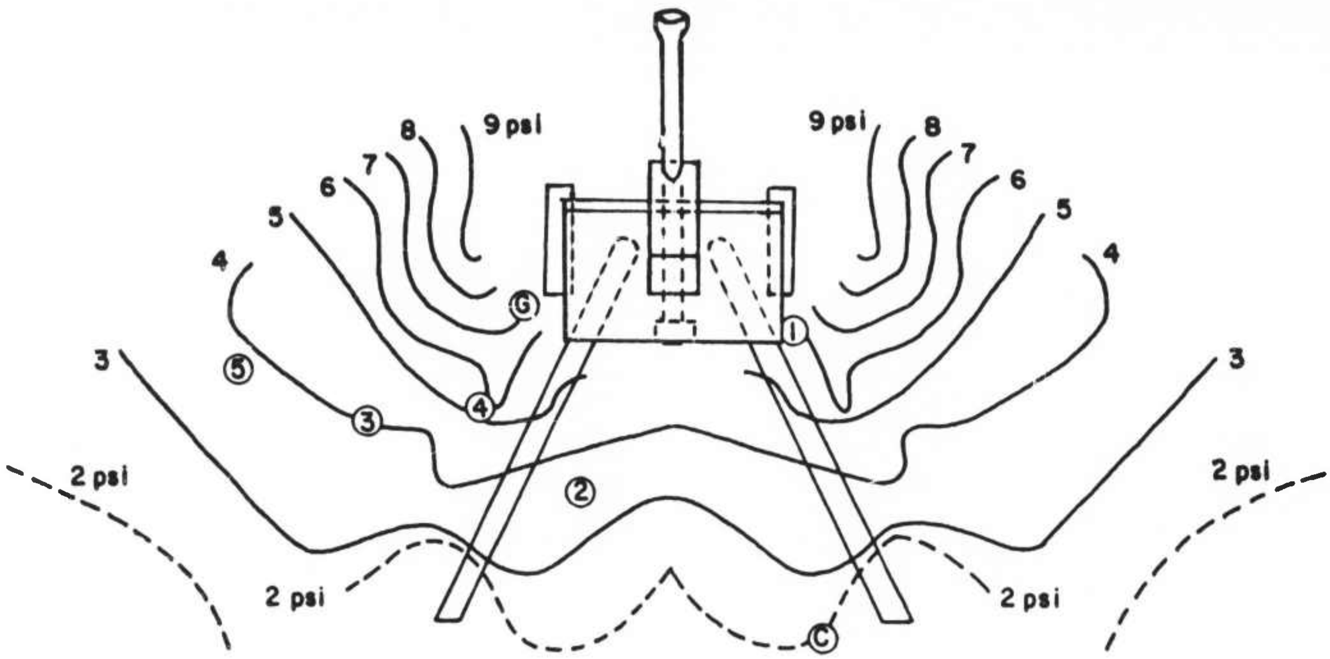


No Blast Shield

Type WTV-F8241 Brake

Zone II - 100 %

Elevation 800 mils

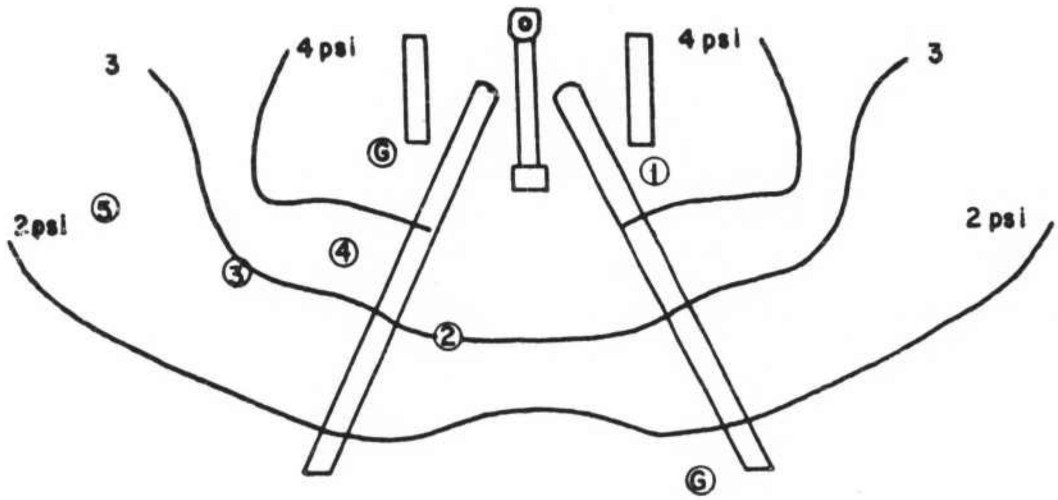


With Blast Shield

Type WTV-F8241 Brake

Zone 11 - 100%

Elevation 800 mils

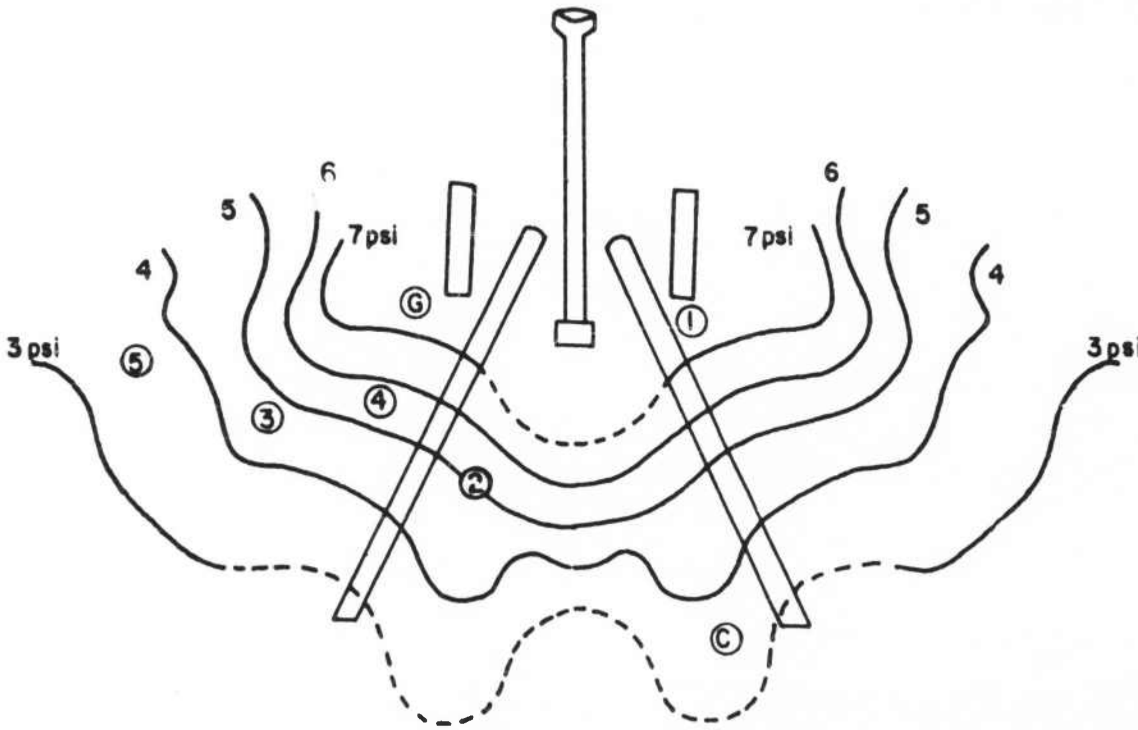


No Blast Shield

Type WTV-F8241 Brake

Zone 9 - 50 %

Elevation 1200 mils

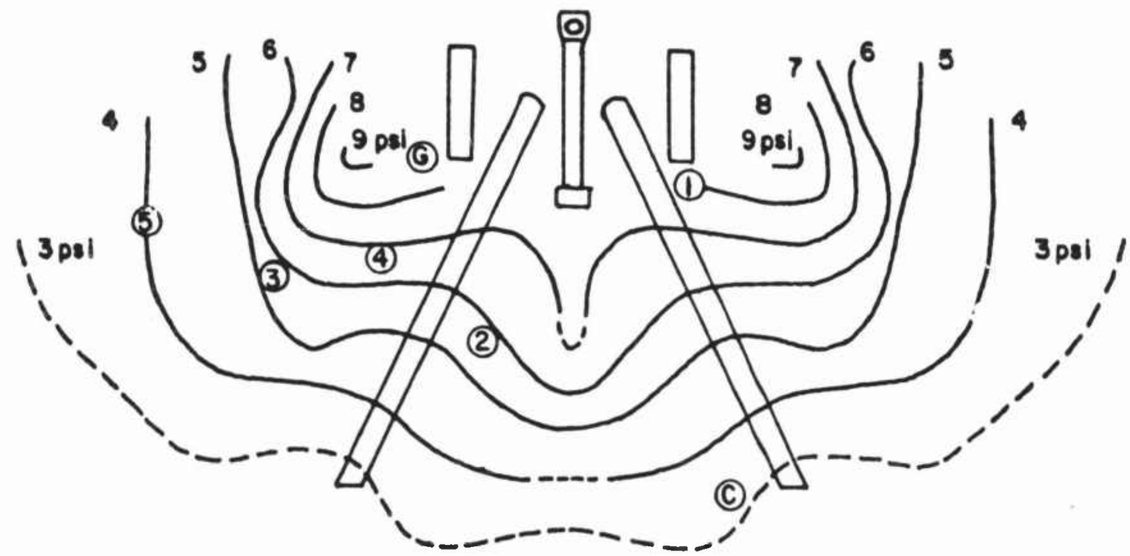


No Blast Shield

Type WTV-F8241 Brake

Zone 10 - 85 %

Elevation 1200 mils

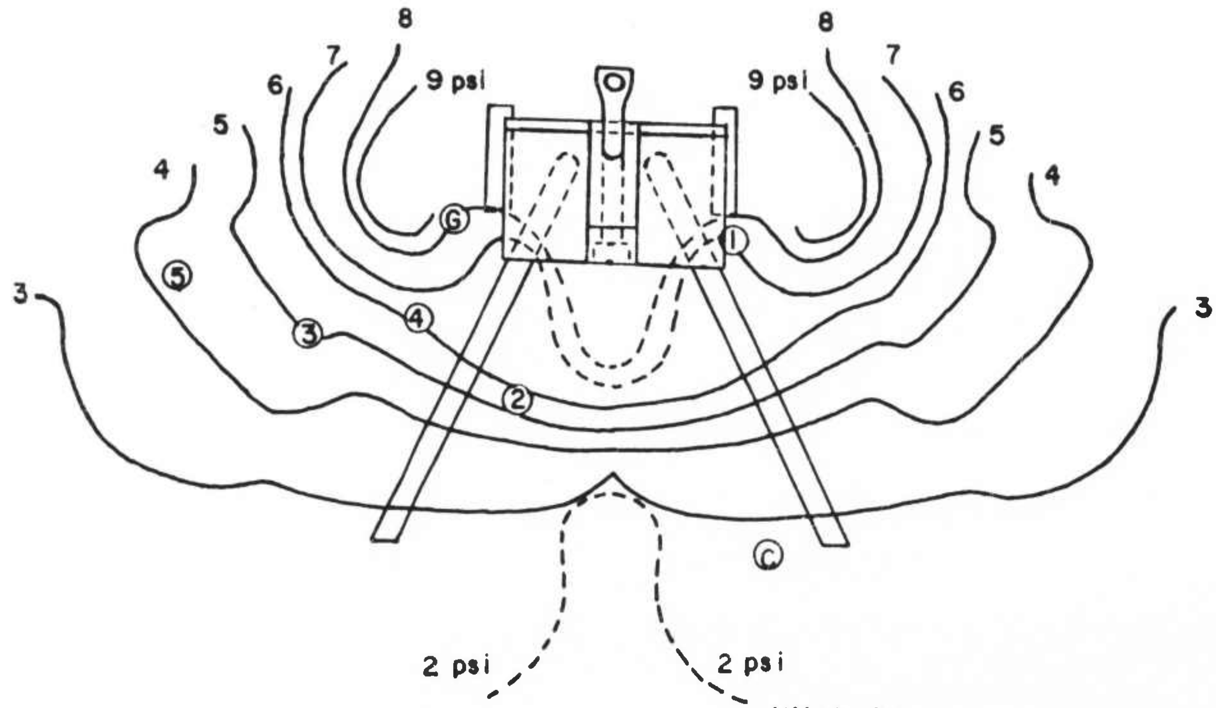


No Blast Shield

Type WTV-F8241 Brake

Zone II - 100%

Elevation 1200 mils



With Blast Shield

Type WTV-F8241 Brake

Zone II - 100 %

Elevation 1100 mils

AD ____________ Accession No. ____________

U.S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland
MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, XM103E1
Howard H. Holland, Jr., Technical Assistance of George W. Mastaglio, October 1962

Unclassified

Tech Memo 23-62 OCMS Code 5520.12.42700.05.01

Measurements of muzzle-blast in the crew area of the 105mm Howitzer, XM103, without a muzzle brake and with muzzle brakes WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), and WTV-D8259 (Low Efficiency), were made to determine the peak overpressures produced. The overpressures produced by the four different brake conditions were one of the most important factors determining which brake would be used on the XM102 Howitzer. The howitzer was fired at elevations of 2, 45, and 62 - 68 degrees.

UNCL

1. Howitzer, 105mm, XM103E1
2. Muzzle Blast Measurements
3. Auditory Acuity

AD ____________ Accession No. ____________

U.S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland
MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, XM103E1
Howard H. Holland, Jr., Technical Assistance of George W. Mastaglio, October 1962

Unclassified

Tech Memo 23-62 OCMS Code 5520.12.42700.05.01

Measurements of muzzle-blast in the crew area of the 105mm Howitzer, XM103, without a muzzle brake and with muzzle brakes WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), and WTV-D8259 (Low Efficiency), were made to determine the peak overpressures produced. The overpressures produced by the four different brake conditions were one of the most important factors determining which brake would be used on the XM102 Howitzer. The howitzer was fired at elevations of 2, 45, and 62 - 68 degrees.

UNCL

1. Howitzer, 105mm, XM103E1
2. Muzzle Blast Measurements
3. Auditory Acuity

AD ____________ Accession No. ____________

U.S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland
MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, XM103E1
Howard H. Holland, Jr., Technical Assistance of George W. Mastaglio, October 1962

Unclassified

Tech Memo 23-62 OCMS Code 5520.12.42700.05.01

Measurements of muzzle-blast in the crew area of the 105mm Howitzer, XM103, without a muzzle brake and with muzzle brakes WTV-F8241 (High Efficiency), 5/K (Medium Efficiency), and WTV-F8259 (Low Efficiency), were made to determine the peak overpressures produced. The overpressures produced by the four different brake conditions were one of the most important factors determining which brake would be used on the XM102 Howitzer. The howitzer was fired at elevations of 2, 45, and 62 - 68 degrees.

UNCL

1. Howitzer, 105mm, XM103E1
2. Muzzle Blast Measurements
3. Auditory Acuity

AD ____________ Accession No. ____________

U.S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland
MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, XM103E1
Howard H. Holland, Jr., Technical Assistance of George W. Mastaglio, October 1962

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